DOCUMENT RESUME

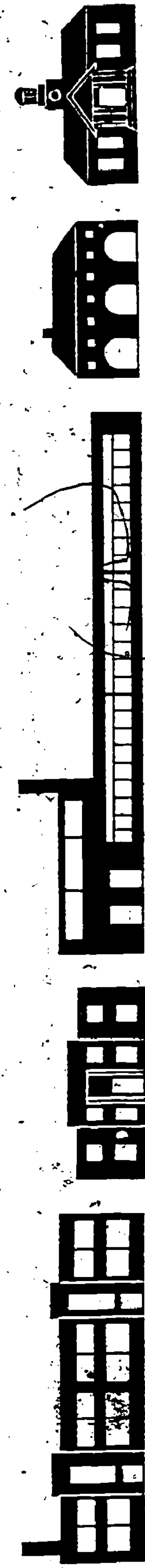
ED 164 296 SE 025 447

TITLE	Energy Management in Municipal Buildings.
INSTITUTION	Massachusetts State Dept. of Community Affairs, Boston. Energy Conservation Project.
SPONS AGENCY	Department of Housing and Urban Development, Washington, D.C.
PUB DATE	[77]
GRANT	HUD-B-75-51-25-000-7
NOTE	158p.
EDRS PRICE	MF-$0.83 HC-$8.69 Plus Postage.
DESCRIPTORS	*Building Operation; Costs; Economics; *Energy; *Energy Conservation; Environmental Education; Heat Recovery; *Local Government; Management; Natural Resources; *Operating Expenses

ABSTRACT

This manual is written for the manager or supervisor responsible for instituting an energy management program for municipal buildings. An introduction discusses the management issues facing municipal government in dealing with the need to reduce energy consumption. The guide reviews methods for central coordination of activity to ensure that resources are wisely applied, that results are communicated, and that follow-up on findings takes place. It defines the techniques of preparation of the energy budget, of organizing and evaluating a building audit, and the management principles involved in selecting among alternative conservation measures to determine the combination most likely to be effective for a particular building. It discusses the human factors involved in changing wasteful practices of building users. A technical appendix provides detailed technical information and formulated work sheets for carrying out techniques presented in the text. (RE)

000 270



energy management in municipal buildings

massachusetts department of community affairs

energy conservation project

Commonwealth of Massachusetts

Michael S. Dukakis • Governor

Executive Office of Communities and Development
Department of Community Affairs

William G. Flynn • Secretary

Robert H. Bateman • Assistant Secretary

Division of Community Services

Ellis Goldman • Administrator

ACKNOWLEDGEMENTS

This manual was prepared by the staff of the Department of Community Affairs Energy Conservation Project under a grant from the U.S. Department of Housing and Urban Development, Innovative Projects Program (Grant No. B-75-51-25-000-7).

This project could not have been accomplished without the cooperation of the municipalities of Attleboro, Concord, and Fall River, and the Northern Middlesex Area Commission, which worked with the towns of Dunstable, Pepperell, and Tyngsboro. These cities and towns provided the project with important data on energy use in their buildings and with access to their buildings for engineering analysis.

The project staff also expresses particular gratitude to the members of the Advisory Committee, whose insights into the operations and needs of local government were invaluable in designing this material. Committee members are listed on the following page.

Development Sciences, Inc., of East Sandwich, Massachusetts, provided consulting services in the development and design of the manual. R. G. Vanderweil Engineers, Inc., of Boston, Massachusetts, provided consulting engineering services for evaluating energy conservation procedures in buildings.

Daniel A. Harkins, Project Director
John R. Haynes, Chief Technical Specialist
Barbara Alfieri, Secretary

ENERGY CONSERVATION PROJECT
ADVISORY COMMITTEE

Name	Affiliation
Paul Levy, Chairman	Massachusetts Energy Policy Office
Gary Beer	Massachusetts League of Cities and Towns
Bert Berger	Boston Society of Civil Engineers
Charles Dinezio	Massachusetts State Building Code Commission
Ray Frieden	Town of Plymouth
James Rennie	Building Management Division, General Services Administration
David Hartwell	Town of Concord
Charles Hill	City of Worcester
Jerry Houghton	Massachusetts Association of School Business Officials
Amos E. Kent	Consulting Engineers Council of New England
Anna Manion	Massachusetts Selectmen's Association
Wayne Marquis	Town of Danvers
Harold Murphy	Boston Chapter, ASHRAE
Robert Philpot	Federal Energy Administration
William Rollinson	City of Attleboro
Raymond Saunders	City of Fall River
Yale Schiffman	American Institute of Planners Energy Task Force
Mitchell G. Tyson	Boston Energy Office
David Worth	Northern Middlesex Area Commission

TABLE OF CONTENTS

AN OVERVIEW FOR THE CHIEF EXECUTIVE

MANAGING THE "ENERGY CRISIS" IN MUNICIPAL GOVERNMENT

As the "energy crisis" unfolded, municipal government in Massachusetts experienced shortages in supplies following the oil embargo in late 1973, the quadrupling of fuel prices that occurred in 1974, and a persistent but less rapid rise in fuel prices since that time. While these events are beyond the control of local government, and their impact on the cost of local government services is severe, government cannot choose to forego providing critical services. Often, a generalized feeling of helplessness has led to acceptance of steadily rising energy costs as a fact of life that must be absorbed in the municipal budget either at the expense of other services or by raising additional revenue.

This need not be the case. Although the price of energy is largely beyond the direct control of municipal government, the amount it uses is not. In most cities and towns energy use in buildings comprises 70% to 80% of the total energy used in all municipal services, including fueling vehicles and lighting streets. Because energy was cheap when the existing physical plant was developed, most buildings use much more than is required to perform their functions. Substantial savings can be made without reducing the level of services offered in these facilities or imposing hardships on their users and occupants. It is theoretically possible to reduce energy use in new buildings by 90% of the prevailing norm in existing buildings. The Energy Conservation Project (ECP) has determined that *it is eminently practical to cut energy use by 30% in many existing municipal buildings.* Achieving this result requires that energy use be managed and controlled to eliminate the margin of waste and inefficiency that exists.

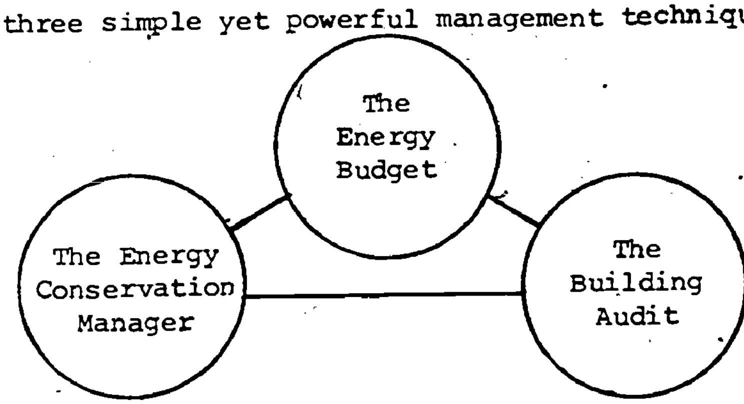
As a chief executive considers whether to organize a program to save energy in municipal buildings, the real nature of the energy crisis should be kept in mind. The fundamental cause is the depletion of domestic petroleum and natural gas supplies that must be replaced at significantly higher prices. Rising energy prices will be a fact of life over the next quarter century. If energy costs rise by an annual rate of 6%, within twelve years the price of fuel will double. Similarly, the energy "saved" each year will increase in value by 6%. Many municipalities that manage their cash reserves would be pleased with a 6% return on these assets. ENERGY MANAGEMENT IN MUNICIPAL BUILDINGS will yield a similar return. It is a program that many cities and towns cannot afford to ignore.

WHAT CAN BE DONE

The Energy Conservation Project worked directly with six Massachusetts cities and towns to evaluate the potential to save energy by reducing consumption in 112 municipal buildings. The results indicated that an effective and sustained program to conserve energy would realize an annual dollar savings in these facilities of $500,000. At least one-half of these savings could be attained at no additional cost. If these savings, which recur each year, were deposited at 6% interest in a savings account, at the end of a twenty year period there would be an accumulation of $18,000,000.

The objective of the ECP manual on ENERGY MANAGEMENT IN MUNICIPAL BUILDINGS is to convey to town managers, selectmen, school officials, and department heads proven approaches to energy conservation in buildings that will yield a significant reduction in annual operating costs for building energy.

The key elements of this program are briefly described in this overview and presented in detail in specific sections of the ENERGY MANAGEMENT IN MUNICIPAL BUILDINGS manual. *These sections are written to enable local decision makers and operating personnel who do not have extensive technical training to organize, implement, and sustain an energy savings program in municipal buildings.* The emphasis this program places on the concept of "energy management" rests on the principle that a large portion of building energy costs are in fact "controllable." An effective program addressing the causes of waste and inefficiency in current building management practices will pay for itself many times over in savings of local tax dollars. The ENERGY MANAGEMENT IN MUNICIPAL BUILDINGS program introduces the tools that are the foundation blocks of a successful program. The program is based on three simple yet powerful management techniques:



The Energy Budget

The energy budget is the method for highlighting those buildings in each city and town where a 30% annual energy savings can be achieved. It is a cost accounting technique that employs performance standards for building energy use to assess the relative efficiency of the entire stock of municipal buildings.

This budgeting technique evaluates building efficiency in terms of total units of energy used per square foot per year. It can be easily translated into dollars to enable a manager to make decisions on program implementation that will yield the greatest dollar return. As energy savings programs in particular buildings are implemented, the Energy Budget remains a useful tool for measuring results. It filters out the effects of fuel price changes and year-to-year climate changes to permit an accurate assessment of how much real progress has been made in each building in a given year and the margin remaining for potential improvement. It provides a manager with feedback on implementation so that successful efforts can be recognized and shortcomings in performance remedied. *The energy budgeting technique does not require sophisticated computer hardware. It can be developed for a building by a clerk with a calculator who has access to the accounting records for vendor payments to fuel suppliers.* The Energy Budget is a technique that every manager can use to pick the targets for an energy savings program that will yield the best payoff.

The Building Audit

There are probably a thousand distinct conservation measures that will save some energy in any given building. Many local programs have floundered from an inability to select program measures that yield the best savings opportunities. ENERGY MANAGEMENT IN MUNICIPAL BUILDINGS specifies procedures that were tested in schools, town halls, fire stations, police stations, etc. and found to work. It reduces the multitude of possibilities to a list of twenty measures described in terms that a layman can understand.

These measures are presented in the form of building audit procedures that can be used to identify the sources of waste and inefficiency in the particular buildings that have been selected as high priority targets on the basis of the energy budget analysis. The building audit is a physical survey leading to the establishment of an energy savings program for each building tailored to fit the savings opportunities that have been uncovered. *Experience in using this approach has shown that usually one-half of the dollar and energy savings can be achieved with implementation of audit recommendations involving little or no cost to the municipality.*

The Energy Conservation Manager

Management is organizing resources and directing people toward a goal. The chief executive of a town government or a school system must focus the responsibility for coordinating and accomplishing the tasks of an energy management program. The options for organizing this management function can vary widely from town to town depending upon the local mix of talent and resources as well as the amount of expected dollar savings in a given community. The program can be managed by a committee of relevant department heads and technical personnel, by an individual who may already have substantial responsibilities in

building management or by an individual hired specifically for this purpose.

ENERGY MANAGEMENT IN MUNICIPAL BUILDINGS identifies what responsibilities need to be specified and assigned. It reviews methods for central coordination of activity to help ensure that resources are wisely applied, that results learned about what works best are communicated, and that monitoring and follow-through do not "fall between the cracks." It defines the technical tasks of information collection and analysis in constructing the energy budget, of organizing and evaluating a building audit, and of selecting the alternative conservation measures most likely to be effective in a given building. No less importantly, it identifies the "people problems" that may be critical in a program seeking to change the ingrained but wasteful habits of building users and occupants.

By addressing these management issues, the manual provides the chief executive with the information needed to anticipate and deal effectively with the human as well as the technical problems that may be barriers to effective management of municipal energy costs.

Six Massachusetts cities and towns participated in developing the ENERGY MANAGEMENT IN MUNICIPAL BUILDINGS program. It is a program that is specifically designed to work in the setting of local government.

A NOTE ON WHAT FOLLOWS

The three sections of this report immediately following are entitled "The Energy Budget," "The Building Audit," and "The Energy Conservation Manager." These are written to provide the manager or the individual with supervisory responsibility for instituting an energy management program with sufficient information to make effective use of the three principal management tools of the program discussed in this overview. Following these sections is a technical appendix valuable to operating personnel involved in program implementation.

In the Technical Appendix, a section on the energy budget discusses some of the finer technical points in converting annual energy consumption into a budget. It includes formulated work sheets that enable an individual to carry out these operations easily.

The appendix presents the key energy conservation measures found to be most effective in municipal buildings. The principles underlying the effectiveness of these measures are presented in easily understood terms. Rules of thumb for estimating the savings that can be achieved with implementation of a given measure are discussed. For some measures that entail capital investment, actual cost/benefit studies are included. These studies were made by the firm of R. G. Vanderweil Engineers, Inc., for the municipalities participating in the Energy Conservation Project study.

TABLE 1

ANNUAL BUILDING ENERGY COSTS IN THE ECP DEMONSTRATION MUNICIPALITIES

City or Town/Characteristics	Major Buildings	Annual Cost of Energy
FALL RIVER	34 Old Schools	$ 535,000.
	5 New Schools	$ 362,000.
Population 100,000	6 Fire Stations	$ 42,000.*
Annual Budget $45,000,000.	3 Town Offices	$ 120,000.*
	2 Libraries	$ 20,000.
	1 Police Station	$ 16,000.*
	1 Garage	$ 7,000.
	Total	$1,102,000.
ATTLEBORO	7 New Schools	$ 440,000.
	8 Old Schools	$ 125,000.
Population 33,000	3 Garages	$ 24,000.
Annual Budget $20,400,000.	2 Libraries	$ 20,000.
	6 Fire Stations	$ 18,000.
	3 Town Offices	$ 15,000.
	1 Police Station	$ 7,000.
	Total	$ 649,000.
CONCORD	7 New Schools	$ 300,000.
	2 Libraries	$ 20,000.
Population 16,000	2 Fire Stations	$ 10,000.
Annual Budget $12,130,000.	1 Garage	$ 7,000.
	1 Town Office	$ 5,000.
	Total	$ 342,000.
TYNGSBOROUGH	2 New Schools	$ 43,000.
	1 Old School	$ 6,000.*
Population 4,313	1 Garage	$ 5,000.
Annual Budget $ 2,510,000.	1 Town Office	$ 4,000.*
	1 Library	$ 4,000.
	2 Fire Stations	$ 1,000.
	Total	$ 63,000.
PEPPERELL	2 Old Schools	$ 25,000.
	1 New School	$ 5,000.
Population 5,887	1 Town Hall	$ 4,000.
Annual Budget $ 2,750,000.	1 Library	$ 4,000.
	1 Fire Station	$ 2,000.
	Total	$ 42,000.
DUNSTABLE	1 Old School	$ 5,000.
	1 New School	$ 4,000.*
Population 1,292	1 Garage	$ 5,000.
Annual Budget $ 1,450,000.	1 Town Hall	$ 2,000.
	1 Fire Station	$ 200.
	Total	$ 16,000.

*Estimated

ENERGY BUDGET

THE DOLLAR COST OF BUILDING ENERGY

Dollars are spent for energy in the form of a varied mix of fuel supplies to heat, light, and power a diverse group of municipal facilities. Compiling the total annual costs by building and by department for all energy used from all sources—whether gas, oil, or electricity—provides a municipality with a useful insight into the structure of its building energy costs.

Table I on the opposite page presents this information for the six municipalities that participated in the ECP study of energy conservation in municipal buildings, summarizing their building inventory and energy cost by department. The Table indicates that building energy costs as a percentage of the total municipal budget range from 1½% to 3% in most municipalities. This percentage range provides a manager who is considering an energy savings program in municipal buildings with a rough approximation of the range of base costs on which a 30% annual energy savings potential can be calculated.

If the departmental building energy costs in a given locality were classified between general purpose government and the school system, on the average the school portion of building energy costs would represent 70% of the total. This emphasizes the importance of school system involvement in a municipality's energy savings program in order to realize the full potential of the program.

In fact, it is quite possible that a large portion of the absolute dollar savings can be found by improving performance of one large, mechanically complex school building. One high school in the ECP study had a quarter million dollar energy budget with an estimated savings potential of 30%.

The absolute dollar cost of building energy will increase with the size of a community, with a corresponding increase in the potential annual dollar savings. Larger cities and towns have greater flexibility to consider changes in the organization of their building management function, including the addition of specially skilled personnel, in order to tap their full annual savings potential.

A municipality beginning an energy savings program may encounter some difficulty in retrieving and presenting energy cost data for specific buildings within a department. As part of a long-term energy management program, a municipality should consider modifying its budgeting and accounting procedures where necessary to build an information

system that will support management action to reduce energy costs in buildings. Figure 1 illustrates the organization of a building management information system. This type of system would ultimately enable a municipality to identify total building energy cost as a line item in its municipal budget with back-up accounts on a departmental and building basis, including data on the cost and units of fuel consumed during a fiscal year. The requisite information elements of such a system and format possibilities for this data are described in greater detail in the appendix.

THE ENERGY BUDGET

Although the dollar budget provides useful insight into the overall structure of municipal building energy costs, it will not indicate which particular buildings represent the best opportunities for cutting energy costs. A comparison of efficiency between two buildings based solely on the dollar cost of energy consumption is subject to serious inaccuracies. The reasons for this are treated thoroughly in the appendix. A comparison on the basis of the total energy used during the same year to heat, light, and power two facilities that have similar uses is a meaningful approach to evaluating relative efficiency. The concept of energy budgeting that will be developed here involves a comparison of actual energy use in each municipal building with a standard of energy consumption for that type of facility. This standard represents what the average building of that type ought to use if it is equipped and operated efficiently. The energy budget provides a manager with a tool for knowing whether the units of energy used by a given facility are well spent, much as miles per gallon provides a car owner with a standard of efficiency in terms of fuel consumption.

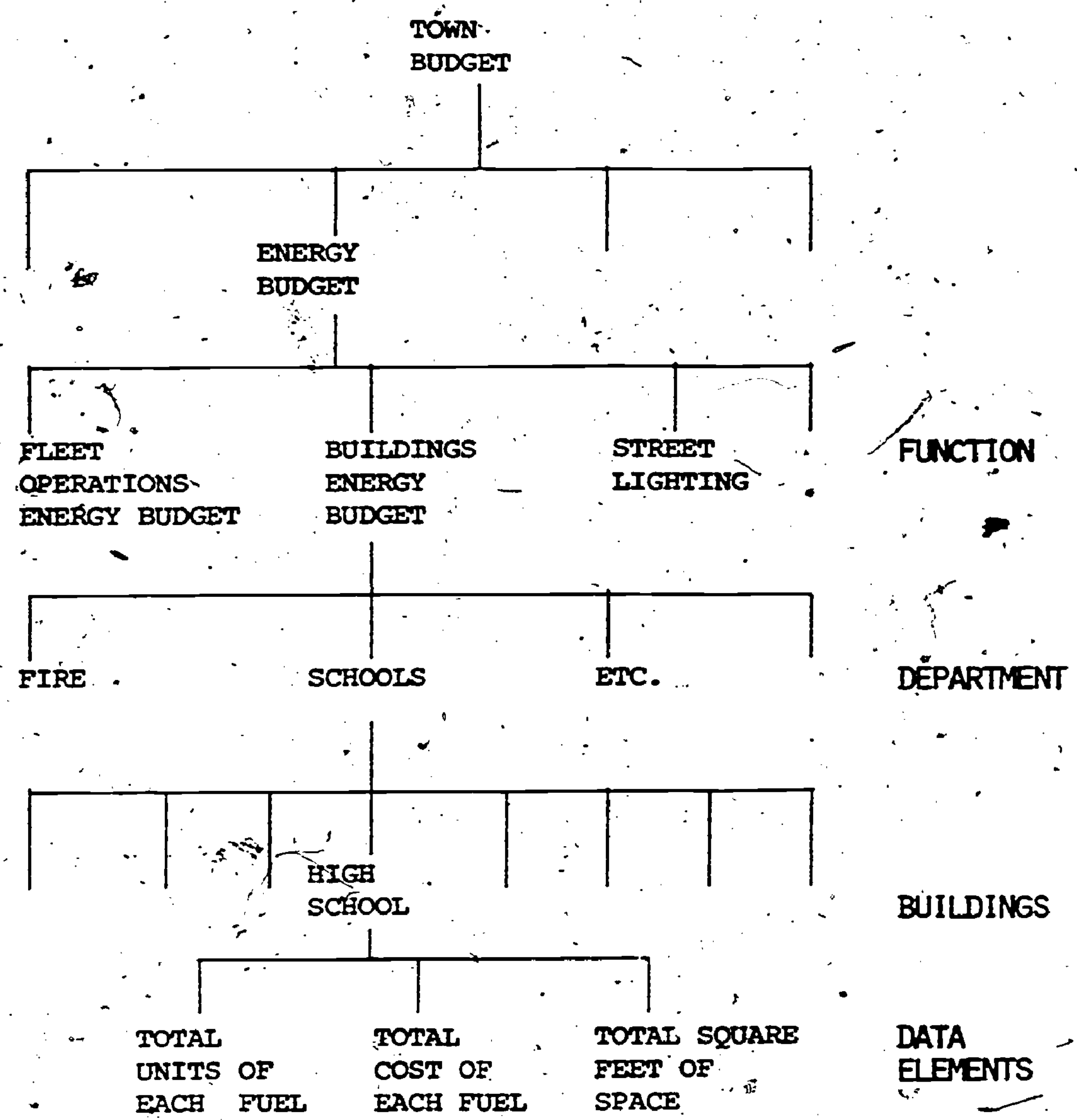
Constructing an energy budget for a building involves the following steps:

1. Obtain accounting records on annual fuel consumption of all energy sources (including electricity, gas, oil) in a specific building and convert these quantities to a common denominator of energy units that can then be added together.
2. Divide this total of building energy used by the square footage of the facility. This yields a measure of energy units consumed per square foot per year.

The figure obtained by the above procedure is in fact a performance indicator that permits the comparison of the relative efficiency of two facilities. The procedure for developing this indicator, including worksheets and conversion factors, is presented in the technical appendix in a simple, easy-to-use form that can be followed by anyone with adequate accounting records and a calculator.

FIGURE 1

ENERGY BUDGET INFORMATION SYSTEM



The unit of energy used to construct this performance standard is the British Thermal Unit (BTU).

A BTU (British Thermal Unit) is a common unit for measuring the heat content of different energy sources such as electricity or oil. It is used throughout this discussion to present different fuels in terms of equivalent heat content. Technically a BTU is the amount of energy needed to raise the temperature of one pound of water one degree Fahrenheit. In more meaningful terms, it takes over 100 million BTU's to heat the typical house during a winter, and over 7 billion BTU's to power a 40,000 square foot school for a year. Since a BTU is such a small unit of measure, the standards and conversion values used in this report are expressed in units of 1,000 BTU's, abbreviated as MBTU's (1000 BTU's = 1 MBTU).

There is a standard MBTU content for each type of fuel. When quantities of different energy sources are converted to their equivalent MBTU values, they can be added together to obtain the value of total annual building energy. By computing MBTUs per square foot per year, an index is obtained that permits comparison of different size facilities having similar uses. In the ECP study of 112 municipal facilities, this index correlated very well with the dollar per square foot cost of energy. The use of this index highlights those buildings where the potential dollar and energy savings are greatest.

THE AEI

This standard of MBTU's per square foot per year is referred to as the Annual Efficiency Index (AEI) of a building. The AEI is the basic tool in energy budgeting that enables a manager to determine whether or not some of the dollars allocated for building energy are being wasted.

The value of the AEI as a measure of performance is dependent on the ability to compare it to a standard of efficiency. An efficiency standard in this sense means that ideally a building of this type should use a certain amount of energy per square foot per year if it is equipped and operated at high standards of energy conservation. The ECP study has developed these standards for particular types of municipal buildings. They are presented in Table 2, expressed as MBTU's per square foot per year for specific types of municipal buildings.

Why are different standards used for different building types? Building usage is a major determinant of energy consumption. Compare how the use patterns of schools and fire stations influence differential energy demands. Buildings have different heating and lighting loads when occupied than when empty. Schools are generally occupied from early morning to late afternoon and may be vacant entirely over three summer months. Fire stations are usually occupied 24 hours a

TABLE 2*

STANDARD (AEI) VALUES FOR MASSACHUSETTS

BUILDING TYPE	BASE AEI STANDARD* (MBTU'S / SQ.FT.)
SCHOOLS BUILT BEFORE 1945	105
SCHOOLS BUILT AFTER 1945	120
FIRE STATIONS	135
TOWN HALLS (OFFICES)	115
LIBRARIES	110
POLICE STATIONS	105
DPW GARAGES	105

* BASE STANDARDS ARE BASED UPON AN ANNUAL HEATING SEASON OF 5621 DEGREE DAYS (BOSTON'S 30 YEAR NORMAL)

day year round and suffer major heat losses in winter when doors are opened for exit and entry of fire trucks. The AEI standards for fire stations are higher than for schools. This does not mean they are less efficient. Comparing the AEI's of schools and fire stations is like comparing apples and oranges. One can only make comparisons of efficiency between facilities that have similar uses.

There is another basic type of difference recognized in Table 2 which presents different AEI's for old schools (pre 1945) and new schools (post 1945). This can be understood by considering that the structural and mechanical differences between a single family house and a high rise apartment building imply different energy demands. Similarly for schools, new schools are heated and ventilated by a sophisticated system of air heating, mixing, and circulating that is mechanically powered, whereas old schools have double-hung windows and radiators. New schools also tend to have more glass area subject to heat loss and ancillary educational facilities such as labs and kitchens that use additional power. The different energy loads for these two types of buildings require distinct AEI standards reflecting these structural and mechanical differences.

HOW TO USE THE AEI

The standard AEI for a building type can be compared with the actual AEI of a building to estimate the potential energy savings in that facility. By expressing the difference between standard and actual as a percentage of actual and multiplying the total annual building energy cost by this percentage, an approximate estimate of the total dollar savings can be obtained. (Worksheets for this calculation are provided in the appendix.)

This total savings estimate represents savings that can be achieved in three ways:

1. Savings that have little or no cost and which can be realized with minimum effort and technical skills on the part of the individuals using and operating the building;
2. Savings that have little or no cost, which can be achieved through a vigilant conservation effort and a higher level of technical skills; and
3. Savings which can be achieved through capital investment in modifying building hardware to improve efficiency and which will be sufficient to at least recover the cost of that capital investment during the lifetime of the building.

The Base AEI Standards and the classification of savings are based upon the work of R. G. Vanderweil Engineers, Inc., which conducted building audits and cost-benefit studies in sixty of the 112 municipal facilities evaluated in the ECP study. A more detailed discussion of

the derivation of the AEI Standards is contained in the appendix.

The Standard AEI should be understood as a goal that can be attained, given a commitment of time, effort, and money. It may not be achieved in the first year of a conservation program, but within two years most of the distance should be covered. Each year's progress can be measured by calculating the actual AEI and comparing it to the local climate-corrected standard AEI for that year. The savings estimate calculated may indicate it is not productive to get every building of a given type right on the standard, but it will pay to get the buildings with highest operating expenses as close as possible.

The manager will want to evaluate the potential annual savings estimate calculated from the difference between actual and standard AEI in both percent and absolute dollar terms. The percent estimate represents the margin of savings potentially available in a given building. The absolute dollar savings corresponds with the actual dollar size of a building's energy budget. A low percent estimate in a building with a large dollar budget may yield an annual dollar savings estimate that is roughly equivalent to a building with a high percent savings estimate but a relatively smaller dollar energy budget.

In using the savings estimates as a guideline for selecting the most opportune targets for a conservation program, managers will tend to select buildings that promise the greatest financial return. Where this means selecting a building with a relatively low percent savings estimate, a greater level of effort may be required, but this can be justified by higher expected dollar return.

In using these savings estimates to select the targets of the energy savings program, managers should first ascertain whether the variance between actual and standard AEI's can be partially explained by an unusual pattern of building use, or the presence of special equipment or facilities in the subject building that differs from the "normal" building of that type. For example, a high actual AEI in a school building might not indicate great inefficiencies if the building is air conditioned during the summer for school sessions.

Some rules of thumb for interpreting the AEI-based savings estimates as a guide for selecting the targets of an energy savings program are conveyed in Table 3.

FOLLOW-UP ON THE AEI

It will be useful to make the AEI calculation each year after the energy savings program is initially implemented, since rising energy prices may obscure any energy savings actually accomplished. The variance should narrow each year as implementation of energy saving

TABLE 3

RULES OF THUMB FOR AEI INTERPRETATION

Possible Annual Savings Estimates	Possible Actions Indicated
The percentage difference between the Actual AEI and the climate corrected Standard AEI is:	
30% +	Building represents best target for an energy savings program. Be sure variance does not reflect differences in use from "normal" building of this type.
10% to 30%	Building represents a good target for an energy savings program. The closer the estimate is to 10%, the more likely that capital investment measures will be needed to reduce energy use to the standard level.
0% to 10%	Building may be operating efficiently. Are there better targets available. Does the size of the dollar energy budget in this building justify its selection as a target even though percent estimate is low?
less than 0%	Check to determine whether there was an error in calculations. Is building used less than the normal building of this type?

measures reduces consumption. Whether this happens is an indication of effectiveness in following through with implementation of the conservation measures that involve changes in operating procedures and modification of the building. In this context, the AEI is a continuing tool for monitoring building performance that will indicate shortcomings requiring remedial attention.

Assuming that the first year effort in an energy savings program is primarily devoted to implementation of no-cost measures, the AEI calculation in program year two will indicate which buildings may yield the greatest return from investment in cost effective measures.

By using the AEI as a method both of selecting the best targets for a conservation effort and of establishing energy and dollar savings goals, the manager has taken the essential first step in implementing an effective energy savings program.

The next phase of the effort is establishing an action program that begins to produce the expected payoff.

BUILDING AUDIT

The Energy Budget provides a tool for selecting, as targets for an energy savings program, buildings that represent the best opportunities for yielding dollar savings. The next phase of the program requires a more finely tuned method to prescribe specific conservation measures which should be implemented in these buildings to achieve this result. This is the purpose of the Building Audit.

The principal concerns for a manager in this phase of an energy conservation program are:

1. Determining which actions are appropriate to specific buildings; and
2. Ensuring that an objective assessment of the savings potential of each possible action in each building is fully considered.

A Building Audit is a "walk-through" of a building by someone trained to identify conservation opportunities. The most important output of an audit is a set of specific recommendations citing the no-cost measures that ought to be implemented in each facility and the capital investment items that should be considered. The audit produces recommendations for an "action" program for each building, based upon physical inspection of operating conditions during the "walk-through."

The recommendations of an audit should include the following:

1. A listing of the energy conservation measures which are applicable in each building in the form of a completed checklist. This list should identify both measures with no implementation cost and those that require capital investment;
2. An estimate of the energy savings to be expected from implementation of the recommended measures. At a minimum, the estimate should separately identify the savings expected from implementation of "no-cost" measures versus savings from measures that will require some investment;
3. For the measures recommended in the checklist, priorities should be assigned to indicate which measures have particularly high energy saving potential; and
4. Finally, the report should note any measures of importance which don't appear on the checklist. These would include special equipment or innovative concepts which the auditing personnel might consider worth further investigation.

One of the most valuable outcomes of the Energy Conservation Project study in which sixty municipal buildings were audited by the firm of R.G. Vanderweil Inc. was the fact that approximately half of the savings estimated could be achieved through implementation of "no-cost" measures.

A sample of the Vanderweil report and its results is presented on the following pages. In this case the auditors worked from a preselected checklist of conservation measures. Since this checklist was designed for audits of municipal facilities, it may be copied for use in any municipality's program. A more detailed discussion of the underlying technical principles on which these checklist items are based is contained in the Technical Appendix. This information will prove useful to the operating personnel with responsibility for follow-through on audit recommendations.

In addition to the items listed in the checklist, the building audit should also include an assessment of the quality of observed building operation and maintenance procedures. Situations where the need for additional or corrective training of operating personnel is apparent should be noted.

ORGANIZING THE AUDIT

The amount of time involved in a building audit, and therefore the cost if outside personnel are used, depends upon the complexity and size of a building and other important factors. The use of a preselected checklist of items can reduce the time required for the "walk-through" and preparation of reports.

Providing outside auditors with well-organized baseline data on each building to be inspected can substantially reduce costs. Key items of information that speed up the auditors' work are:

- annual energy consumption data by type of fuel and amount;
- the square footage of the building and normal hours and seasons of operation;
- type of construction, with emphasis on number of stories, glass area, and type of wall and roof insulation, if any; and
- major characteristics of the heating and lighting systems.

Providing outside personnel with this information rather than having them spend time in developing it saves money.

Another key to organizing efficient Building Audits is the presence of operating and supervisory maintenance people during the audit, since the auditor will have detailed questions on equipment and operating procedures. Their cooperation is essential, since they know most about their building and will be the people who must implement many of

Dear Sirs:

Enclosed are the reports of our audits of your municipal buildings. These audits consisted of field visits by one of our staff engineers to determine the applicability of a preselected list of energy conservation measures.

In the checklists that follow, our observations and recommendations are indicated in the following manner. For measures found to be applicable we noted whether the measure should receive high priority (designated by "H") or low priority ("L") in implementation efforts. Check-offs are used to indicate:

1. measures which appear to have applicability but which require more analysis than a walk-through audit;

2. measures which have no cost to implement (such as changes in operating procedures;

3. measures judged not applicable in specific buildings; and

4. measures which were already implemented at the time of the walk-through audit.

Our report includes estimates of the savings in energy consumption in three categories:

1. Percent savings from measures already implemented in the building when applicable;

2. Percent reduction that would result from implementation of the recommended no-cost measures;

3. Percent reduction in energy that would result from cost-effective investments in equipment which would make permanent improvements in the building performance. In this case we have noted areas where further engineering study is warranted to determine whether these improvements should be undertaken.

Personnel motivation is probably the most important factor in energy conservation. We believe that in most cases aggressive management could result in an additional 5 to 10 percent in no-cost savings.

Savings estimates and reports on each of the buildings follow.

Based on our walk-through survey of the High School the following items are likely subjects for further cost-benefit analysis:

1. Conversion of oil to gas boilers;

2. Excessive ventilation of unit ventilators;

3. Roof insulation and reflective coating on outside windows;

4. Heat recovery from boiler stack.

Attached is our walk-through check list. Implementation of the no-cost measures will result in an estimated reduction in energy consumption of 15 to 20 percent. Although the above cost-benefit studies are not complete we estimate that another 15 to 20 percent reduction through cost-effective investment is possible. Measures already implemented by local personnel have resulted in 15 percent reduction in energy consumption.

R. G. VANDERWEIL
Engineers, Inc.

AUDIT CHECKLIST

DATE: 6/9/76

TOWN: Wattsville

BUILDING: High School

MEASURES	NOT APPLICABLE	ALREADY IMPLEMENTED	RECOMMENDED *	REQUIRES FURTHER STUDY	NO COST MEASURE
1) Set back indoor temperatures during unoccupied periods to a recommended level of 55			H		X
2) Shut down ventilation system during unoccupied periods		X			
3) Reduce ventilation rates during occupied periods			H	X	
4) Reduce conductive heat loss transmission through the building envelope by adding wall insulation, roof insulation and storm windows			L	X	
5. Measure the burner-boiler/furnace efficiency to ascertain that boiler is operating with a combustion efficiency of 75 to 80%			H		
6) Reduce consumption of hot water through low flow shower heads and automatic shut off lavatory faucets			L		
7) Add timeclock to recirculating system		X			
8) Turn off cooling system during unoccupied periods		X			
9) Use switching and timers on school lights by installing recommended devices in these locations		X			
10) Reduce power for lighting by disconnecting ballasts when delamping			H		X
11) a. Maintain steam traps every 3 months		X			
b. Check filters on central air handling units and replace every month		X			
c. Insulate distribution in the following areas None		X			
d. Eliminate reheat	X				
12) Check window units and chillers.		X			
13) Use outdoor air for cooling.		X			
14) Reduce winter indoor temperatures during occupied periods to a recommended level of 68°.			H		X
15) Increase summer indoor temperature and relative humidity levels during occupied hours up to a recommended maximum of 78/60%.			H		X
16) Reduce hot water temperatures to a recommended temperature of 110°.			H		X
17) Reduce solar heat gains through addition of blinds, curtains, etc.			H		X
18) Reduce illumination levels by replacing existing lamps with ________ or by removing about 1/3 of lamps from existing fixtures in Administrative area.			H	X	
19) Turn off lights in unused areas.			H		X
20) Use task lighting in the areas of Administration.			H	X	
21) Utilize daylight for natural illumination in the following locations: Library, Shops			H		X
22) Reduce energy consumption for equipment and machines by adjusting the following equipment: ________	X				
23) Reduce electric demand by turning off A/C units.	X				
24) Install separate domestic hot water heater.		X			
25) Check controls calibration.		X			

* In the RECOMMENDED column, "H" indicates high priority; "L" indicates low

the recommendations. Involvement of the individual who has supervisory responsibility for the user group occupying the building (such as a school principal) is advisable, since implementation of some of the no-cost measures will require user cooperation. This individual can also provide information on scheduling requirements.

In general, an audit should be organized to ensure that sufficient information on the mechanics of a building and user requirements is readily available to those conducting it.

Ideally, the audits should occur well into the heating season when buildings are fully occupied. This will assure that the buildings are observed in their normal modes of operation. For air-conditioned buildings that are occupied in summer months, a follow-up audit should be made at that time as well.

SELECTING BUILDING AUDITORS

There are two options for selecting personnel to conduct the building audit—using in-house personnel or hiring outside consulting engineers. A municipality should make the choice based on its own assessment of financial constraints and the skills of its in-house personnel. Under no circumstances should a municipality forego conducting building audits because it doesn't have the money to hire outside personnel. Remember that one half of the savings found in the Energy Conservation Project study resulted from easy to identify no-cost measures. There is sufficient information available in this report to enable a municipality to capitalize on these savings opportunities and to identify the items that might be subjects of cost/benefit analysis at a later time when funds are available.

The level of skills required in auditors correlates with the mechanical complexity of the buildings to be evaluated. Older buildings without climate control systems do not require a great deal of sophisticated analysis. Buildings with mechanical ventilation and air conditioning, as is the case with many new schools, should be audited by an individual with a sound background in these systems.

Where a municipality has the option of considering outside personnel, it should ascertain that the firms or individuals under consideration have a background in energy conservation activity.

It would be ideal for a trained engineer who is professionally qualified in the design and maintenance of mechanical and electrical systems for buildings to conduct the building audit. An engineer will be able to spot potential sources of energy waste quickly, whether they be due to mechanical problems or to improper operation and maintenance procedures.

Among the advantages of using outside consultants are the benefits of an unbiased observer who can often recognize inad[illegible]acies in building

operation and maintenance better than local personnel.

Outside help is also the best means of getting an analysis of any weaknesses that may exist in the technical skills of staff with operating responsibilities for mechanical systems. This is particularly the case with sophisticated mechanical systems found in modern schools. A large high school may have a quarter million dollar annual energy budget. Here a 10% savings is highly significant, and tight operation of control systems can easily achieve it. An outside audit signals to employees a departure from business as usual and as such can enhance their motivation to follow through.

There are several sources of outside technical assistance that might be considered. Conceivably local citizens with mechanical engineering skills might be persuaded to volunteer time to a program. Major town industries, including the utilities, may have personnel with the requisite skills that could be made available at no cost to the municipality. Professional engineering firms are a source available at a fee. Firms with experience in this field should be confident enough to guarantee that the cost of their services will be recovered through savings within a period following implementation of their recommendations. The cost of using outside services can be minimized if the key audit information is collected in advance and is available to the firm. Similarly, costs may be held down if the audit is split into two levels of analysis. The first level would be a survey citing no-cost measures to be implemented and capital investment items to be considered but not evaluated on a cost/benefit basis until the second level. The Technical Appendix to this report can be used to select capital investment measures that are most likely to have the best payoff when verified by a detailed cost/benefit study at an additional fee.

FOLLOW-THROUGH ON THE AUDIT

Although the audit produces recommendations, the dollar and energy savings will only be realized with implementation. Some of these savings are only available after investment in modifying the physical plant of a building. But there is an immediate and substantial payoff from implementation of the no-cost measures. Follow-up attention by the manager to make sure that these recommendations are implemented promptly is essential.

The ECP study was able to reduce the content of no-cost recommendations on an audit checklist to sixteen procedures that are common to the operation of most municipal buildings and have the biggest impact on savings at little or no cost. They can be usefully classified here by the type of follow-up action required of a manager when implementation is recommended by an audit. The following reviews a classification scheme that notes the different focus for management follow-

through suggested in each category:

1. Measures which involve minor changes in the operation and maintenance of buildings, but can be accomplished without special training of building operating personnel. These measures include:

   a. Set back thermostats during evenings and on weekends to a recommended setting of 55 degrees;

   b. Shut down ventilation system during evenings and on weekends;

   c. Shut down cooling system completely during evenings and on weekends;

   d. Reduce unnecessary lighting by delamping (i.e., removing selected bulbs from their fixtures); and

   e. Reduce domestic hot water temperature to 110 degrees.

   Follow-through:

   Items a through c can best be implemented by adjusting mechanical timers and controls in a building. If these controls are not available, then set-backs should be made part of standard operating procedures for personnel.

   The indicated degree settings are critical to getting the full potential payoff.

2. Measures involving changes in the operation and maintenance of buildings which require technical assistance or special skills from operating personnel. These include:

   a. Reduce ventilation rates during occupied periods;

   b. Measure and adjust efficiency of the boiler/burner;

   c. Check calibration of thermostats;

   d. Eliminate reheat; and

   e. Disconnect ballasts when delamping.

   Follow-through:

   If requisite skills are not available on staff, items a, b, and c can be done under an annual maintenance contract. Items d and e can be handled by an experienced mechanic.

3. Measures which can be initiated by building operating personnel but which require the cooperation of all users of the building for effectiveness. These include:

   a. Reduce winter indoor temperature to 68 degrees or lower;

   b. Increase summer indoor temperature to 78 degrees or higher;

   c. Turn off unused lights;

   d. Use outdoor air for summer cooling;

e. Use blinds or curtains to reduce solar heat gain in summer; and

f. Use natural lighting whenever possible.

Follow-through:

These items have a substantial payoff and the cooperation of building users on a day to day basis is absolutely critical. Explicit and continuing efforts to enlist that cooperation are advisable. An introductory meeting to review the overall goals and objectives of the municipality's conservation program with building users should be considered. Most people will accept a 68 degree thermostat setting if they understand that the choice is between wearing warmer clothing, such as a sweater, or reducing vital municipal services. Similar appeals can be made for observance of each of the above measures. A periodic checkup of each building to ensure compliance also ought to be considered.

FOLLOW-THROUGH IMPLEMENTATION OF CAPITAL INVESTMENT MEASURES

Each building audit will uncover a number of possibilities for saving energy by modifying building equipment and the building envelope. The list of possible capital investments can be evaluated using engineering and financial criteria. The annual energy savings that will result from a given improvement can be estimated and converted to a dollar value representing the expected annual return on the cost of that investment. The manager using financial criteria such as years to payback and rate of return can select those investments which will yield a return over and above the original cost of the investment. This return could be thought of as an annual dollar savings that could be reinvested in additional energy conservation improvements until the list of possible cost-effective improvements has been completed.

A manager can obtain a financial and engineering analysis of the list of possible investment measures that will provide him with information on the cost of the investment, the annual dollar savings, and the expected lifetime of the improvement. On this basis, a schedule of capital improvements can be organized. These can be selectively implemented each year as funds are available until all cost-effective investments have been made, reducing annual building energy costs to a minimum.

The Building Audit program in six municipalities in the ECP study included a financial and engineering analysis of a list of thirty possible energy conservation improvements in different municipal buildings. These studies, and a detailed presentation of the financial decision-making criteria that can be used to evaluate improve-

ments, are contained in the Technical Appendix.

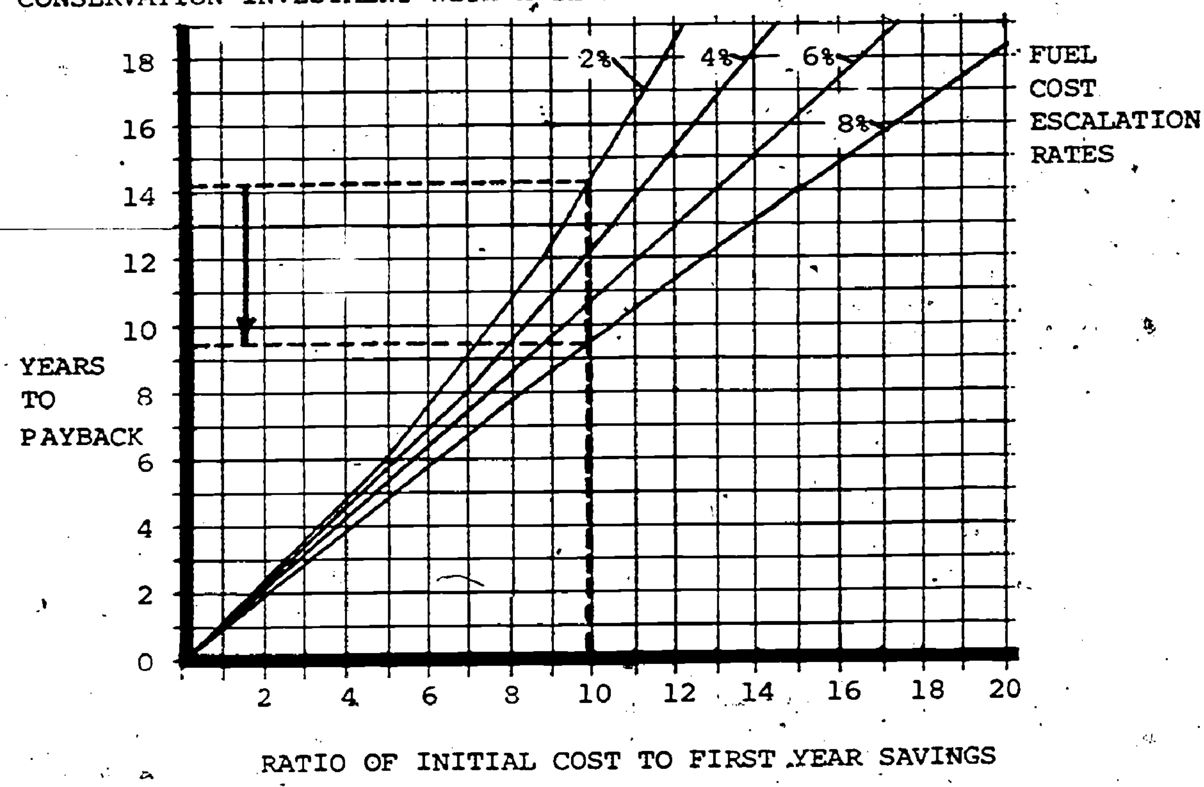
There are two very important points to make in closing this discussion. Because of the inefficiency of our current building stock, there are investment opportunities for improving municipal buildings that yield a better overall return that can be obtained by investing the same amount of money in a savings account. By not identifying these opportunities and making these investments, a municipality will be forced to spend an increasing amount of money each year for building energy that is being unnecessarily wasted.

The latter point must be stressed. Rising fuel prices are inevitable for the foreseeable future. The only uncertainty is how rapidly they will increase. This means that the annual savings anticipated from an improvement will increase at the same rate as fuel prices escalate. The effect of this is a much quicker return on investment than would otherwise be the case. This is illustrated by the graph in Figure 2, which charts "years to payback" versus the ratio of initial investment cost to annual savings. The heavy dotted line shows, for an investment of (for example) $1,000 with annual savings of $100 (i.e., a cost to savings ratio of 10 on the horizontal axis), how the years to payback decrease as the rate of fuel price escalation increases.

This is a rather high cost/savings ratio. There are investment opportunities in many municipalities with a much quicker return.

FIGURE 2

TIME REQUIRED TO RECOVER AN ENERGY CONSERVATION INVESTMENT WITH A SEVEN PERCENT DISCOUNT RATE



ENERGY CONSERVATION MANAGER

Organizing a program of energy management in buildings requires leadership by the Chief Executive in assigning to municipal personnel the key tasks to be performed in energy budgeting, building auditing, and follow-through phases. The participants in these activities will be a diverse group of individuals. Motivating them, coordinating their efforts, and recognizing their accomplishments is the key to the long-term success of the program.

ROLE OF THE MUNICIPAL ENERGY CONSERVATION MANAGER

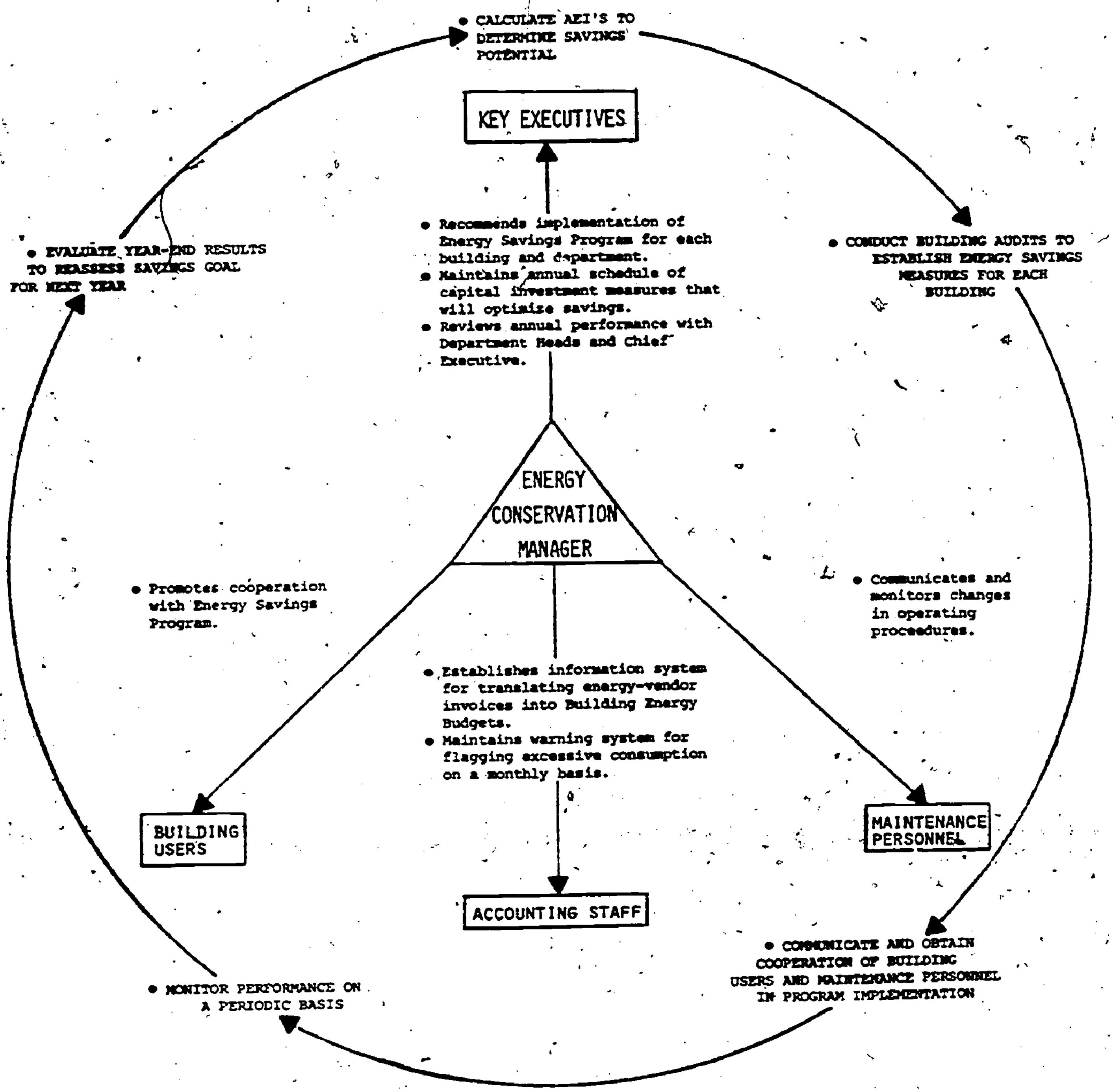
An important first step that will give the program needed visibility is a formal policy statement by the chief executive announcing program goals and objectives and assigning responsibility for implementation of key tasks. These tasks can be thought of as a sequence that includes: calculating AEI's to determine energy savings potential; communicating with and obtaining the cooperation of maintenance personnel and building users involved in program implementation; monitoring performance on a periodic basis; evaluating year-end results; and reassessing savings goals for the next year. The individuals involved in these activities include the chief executive, accounting personnel, maintenance personnel, and building users.

There is an obvious need for coordinating this effort. In evaluating the options for accomplishing this, the chief executive should consider the integrated role that can be played by a locally designated Energy Conservation Manager. The illustration on the following page schematically presents this concept. The diagram does not necessarily imply the addition of new personnel. This function may be appropriate to an individual already on staff or to a department that already has building management responsibility. It is important that the program functions be explicitly assigned and that the assignment carry with it sufficient visible support from the chief executive so that the responsible individual or department with the assignment can obtain the cooperation of the key actors.

The people-oriented aspects of the Energy Conservation Manager's role need to be stressed. The cooperation of maintenance personnel and building users such as classroom teachers in adjusting to changes in operating procedures and wasteful habits is vital. The tasks that are

FIGURE 3 ROLE OF THE ENERGY CONSERVATION MANAGER

Annual Program Cycle



important to the success of this communication process are highlighted below:

Interpreting and Promoting the Program:

1. Translate target goals and walk-through audit results into building operation procedures for each building maintenance person;
2. Assess the practicality of implementing these procedures to determine when and how much training or outside assistance is needed; and
3. Meet with user groups to educate them in the municipal energy savings program and its implications.

Implementing the Program:

1. Communicate building operations procedures to building operators and managers;
2. Communicate energy consumption data regularly to building personnel and administrator;
3. Communicate problems in interpretation or implementation noted through periodic monitoring to the administrator; and
4. Communicate examples of successful results in saving energy and dollars.

ESTABLISHING THE ENERGY CONSERVATION MANAGER'S ROLE

The decision on where to assign the Energy Conservation Manager's function must take into account the local circumstances of organizational structure, skill levels of personnel, and financial constraints. As the task definitions show, the ECM needs to have skills in motivating and communicating with people, as well as a background in building operations. One way of evaluating the worth of this function is estimating the extra margin of savings that can be generated with aggressive program implementation. This would be considered as roughly 10% of a municipality's total building energy cost. The impact of this savings increment is shown in Table 4 for the six municipalities that participated in the ECP study.

Ten percent is a very conservative estimate of potential savings and could easily be reached through no-cost measures. The Energy Conservation Manager in Concord successfully reduced energy consumption in the Town Hall by 30% over one year at no cost. Observe that for towns over 10,000 in population an annual savings of even 10% would amply provide the salary of an energy conservation coordinator.

The degree of control exerted by one energy coordinator over the operation of all municipal buildings may vary among municipalities. Traditionally the operation of municipal buildings falls under

TABLE 4

Town	Population	Total Cost of Building Energy	10 % Annual Savings
Fall River	100,000	$ 1,102,000	$ 110,200
Attleboro	33,000	$ 649,000	$ 64,900
Concord	16,000	$ 342,000	$ 34,200
Tyngsborough	4,313	$ 63,000	$ 6,300
Pepperell	5,887	$ 42,000	$ 4,200
Dunstable	1,292	$ 16,000	$ 1,600

departmental control (i.e., the school department exclusively controls school buildings, the fire department operates its own buildings, etc.). However, if one accepts the savings opportunities described earlier, it may be well worth changing the traditional scheme of municipal operation to gain the benefits of expert skills available through central building management.

On the other hand, by making the energy conservation manager something less than all-powerful, the position may become more feasible without sacrificing a great deal in effectiveness. For example, school buildings account for about 70% of the energy used in all municipal buildings. By making the Energy Conservation Manager (ECM) a part of the school department, a major portion of the town's potential savings could be achieved. This is but one example of the many possible ways in which a municipality can build the role of an ECM into its existing organizational structure. Given the variations in the structure of local governments in Massachusetts, there is no single best organizational approach; the municipality must determine for itself how and where the ECM should fit in.

The ECM should be located to serve all municipal departments having building management responsibilities and thus generate the greatest savings. Ideally the ECM would function in every department, and should always function in school buildings.

One of the most important conclusions drawn in the ECP study of 112 municipal buildings was that achieving the highest possible margin of energy savings depends on aggressive implementation. In most cities and towns, an energy conservation manager with the responsibility and the authority for getting the job done can achieve additional savings that will more than cover any additional salary costs involved.

TECHNICAL APPENDIX

REVIEW OF BUILDING ENERGY BUDGETING PRINCIPLES

This section discusses the following technical issues:

Why units of energy are used rather than dollars in budgeting;

Why the AEI is adjusted for building size and cost of fuel; and

How the Standard AEI's were derived.

This section also presents the methods and material, including sample worksheets, for calculating AEI budgets.

Why Units of Energy Rather than Dollars are Used in Energy Budgets

A comparison of the efficiency of two separate buildings should be made on the basis of the total units of energy required for heat, light, and power in the respective buildings. The alternative comparison, based solely upon total dollars spent for energy in buildings, is subject to serious inaccuracies for two reasons.

First, the prices of different sources of energy (i.e., electricity, oil, and gas) are not equivalent in terms of units of energy per dollar, and different buildings use these sources in varying proportions. Energy units purchased in the form of electricity, for example, are three times as expensive as those in the form of oil. It is conceivable that two buildings could have significantly different energy bills while consuming equivalent amounts of energy.

Second, because energy prices increase from year to year, comparing a particular building's total dollar energy cost in succeeding years may obscure the fact that actual annual energy consumption has remained the same or even decreased.

The relationship of energy sources (i.e., electricity, gas, and oil) to end uses (heat, light, power) in one building is not likely to be the same as in another. And within the same building, one source may be substituted for another over time. It is not very useful for efficiency purposes to compare quantities (i.e., gallons, kilowatts, cubic feet) of energy sourses consumed between buildings. But the energy content of different fuels is known and can be measured in thousands of British Thermal Units (MBTU's). (A BTU is defined as the amount of energy required to heat one pound of water by one degree fahrenheit. An MBTU is equivalent to 1,000 BTU's.), When quantities of different fuels, such as kilowatts of electricity, gallons of oil, and cubic

feet of gas, are converted to their MBTU equivalents, they can be added together to determine the total MBTU's of energy used in a building during a year. (The only real adjustment the layman has to make in thinking about energy sources in BTU's is the problem of scale. BTU's are a small unit of measure. There are 143,000 BTU's in one gallon of oil. During the course of a year, a given building will consume several billion BTU's.) Totalling the BTU's of energy used during a year in a building presents a much more accurate picture of consumption and permits accurate comparisons between similar types of buildings.

Adjusting the AEI for Building Size and Cost of Fuel

Energy use in a building is partly a function of the volume to be heated and the square footage to be illuminated. Dividing total annual energy use by total building square footage allows comparisons to be made between different size buildings. This measure of MBTU's per square foot is a performance indicator that is a rough measure of relative building efficiency. In this report, total MBTU's per square foot is referred to as an Annual Efficiency Index (AEI). The AEI is the basic tool in energy budgeting that enables a manager to determine whether or not the dollars allocated for building energy are being wasted.

Since it is intended that this budgetary technique attract a manager's attention to buildings with the greatest dollar savings as well as energy savings potential, the conversion factors used are adjusted for the fact that, as a rule, electrical MBTU's are three times as expensive as oil or gas MBTU's. In the ECP study, this corrected AEI yielded the best correlation with dollar per square foot cost, and is accurate for buildings that use fossil fuels for heating.

All-electric buildings will generally have inflated AEI's when compared directly to similar fossil-fuel-heated buildings. This does not mean that all-electric buildings are actually more inefficient than their fossil-fueled counterparts, but rather that electricity—as an energy source—has built-in inefficiencies due to the large energy losses associated with its generation.

The AEI standards recommended in this manual are for fossil-fuel (gas or oil) heated buildings only and should not be applied to all-electric buildings. (It is possible to adjust the AEI of an all-electric building, if the annual electrical consumption for space heating alone can be isolated from the total electrical consumption. However, since all-electric municipal buildings are relatively rare in Massachusetts, this adjustment is not included.)

How Were the Standard AEI's Derived?

The ECP study calculated AEI's for 112 municipal buildings. These buildings were grouped by type and an average AEI for the group was calculated. The AEI of each building was then compared to the average, and sixty buildings found to be significantly above average were

selected for a Building Audit to determine the causes of their inefficiencies. These audits examined operating procedures and mechanical equipment in each building. Each inspection resulted in a report that indicated which procedures should be modified to improve efficiency and where improvements in equipment would reduce consumption. The percentage savings in annual consumption that would result from these procedural modifications, i.e. no-cost savings, were also estimated for each building.

Taking these estimates into account, new average AEI's were calculated for each building type. Climatic adjustments were also factored in to account for the geographic dispersion of the demonstration municipalities. These new average AEI's, adjusted to the Boston climate, are the base AEI standards. By readjusting the standards to reflect local climates (see Step III in the next section), these AEI standards may be applied in all of the cities and towns of Massachusetts.

PROCEDURES AND WORKSHEETS FOR CONSTRUCTING AN ENERGY BUDGET

The municipal building energy budget is composed of energy budgets of each municipal department, which in turn are constructed by aggregating the energy budgets of each building. The preparation of an energy budget for a building is a four-step process summarized in Figure I-1 and discussed below.

Step I: Collect Data

The required data, which consist of the total quantities of electricity, oil, and natural gas consumed annually as well as their costs, can be obtained in one of two ways. The first way, which is probably more likely to be accurate than the second, entails personally collecting the monthly utility bills and oil delivery receipts for the most recent fiscal year directly from municipal records. The alternative is to submit a request for a yearly summary of the municipal accounts to your utilities and oil dealers. These requests may be refused, however, since the information you request is made available through the normal billing process.

To facilitate the collection of this data, use Worksheet 1. Copies of this worksheet should be prepared for each municipal building. Retain the completed worksheets for your permanent records.

Also required in the energy budget is the enclosed area of the building, which can be determined either from the building plans or, if they are unavailable, by physically measuring the building. Count each floor separately in the measurement, but don't include unheated basements or attics. Deduct the thickness of the exterior walls from the measurements, but leave in the space occupied by interior walls. Figure I-2 shows the correct method of measuring building area using a

FIGURE I-1 PREPARING AN ENERGY BUDGET

PROCESS STEPS	USE WITH:
I. COLLECT DATA -*COLLECT* twelve months fuel consumption data (gas, oil, electricity).	WORKSHEET 1
II. COMPUTE ACTUAL AEI -*CONVERT* fuel consumption to equivalent energy value in MBTU's. -*DIVIDE* total energy value by total building area.	WORKSHEET 2
III. COMPUTE STANDARD AEI -*MULTIPLY* base AEI standards by local climatic adjustment factor.	WORKSHEET 3
IV. DETERMINE POTENTIAL ENERGY SAVINGS -savings factor = $\frac{\text{actual AEI} - \text{standard AEI}}{\text{actual AEI}}$ -dollar savings = savings factor X total annual energy cost	WORKSHEET 4

SAMPLE WORKSHEET 1

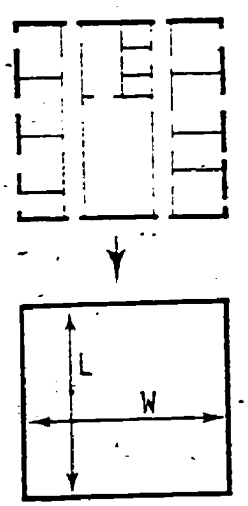
FUEL CONSUMPTION DATA WORKSHEET

MUNICIPALITY: WATTSVILLE
BUILDING NAME: JUNIOR HIGH
FISCAL YEAR: 1974-75
BUILDING AREA: 50,120
TOTAL ANNUAL ENERGY COST: $31,800
TOTAL ANNUAL ENERGY CONSUMPTION (MBTU'S): 10,154,060

MONTH/YEAR	NATURAL GAS CONSUMED (CCF)	NATURAL GAS COST (DOLLARS)	#4 OIL CONSUMED (GALLONS)	# OIL COST (DOLLARS)	# OIL CONSUMED (GALLONS)	# OIL COST (DOLLARS)	ELECTRICITY CONSUMED (KWH)	ELECTRICITY COST (DOLLARS)
JUNE			0	0			14070	934
JULY			0	0			8200	544
AUG			0	0			10100	670
SEPT			0	0			19050	1265
OCT			3315	1061			24770	1645
NOV			6444	2062			25800	1713
DEC			9760	3123			24,040	1596
JAN			10,030	3210			24770	1645
FEB			6630	2122			26100	1733
MAR			10025	3208			26000	1726
APR			3130	1002			22100	1467
MAY			0	0			17000	1129
TOTALS:			49,334	15,733			242,000	16,067

FIGURE I-2 CALCULATING BUILDING AREA

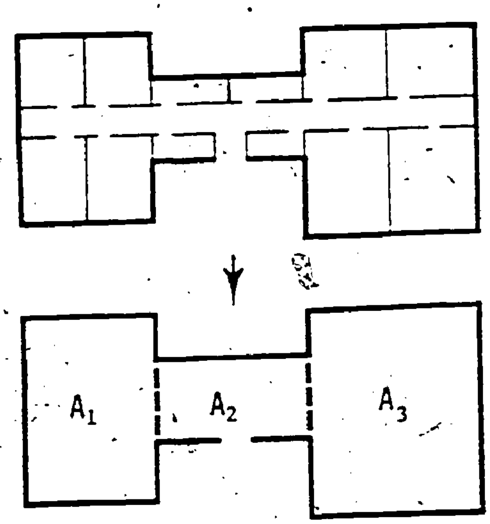
1.
FROM THE PLANS OR A VISIT TO THE BUILDING



MEASURE THE OVERALL LENGTH AND WIDTH OF THE BUILDING IGNORING INTERIOR WALLS

AREA = L x W

2.
IN MORE COMPLICATED BUILDINGS



BREAK THE BUILDING INTO SIMPLE RECTANGLES
AREA = $A_1 + A_2 + A_3$

DON'T FORGET TO ADD THE AREAS OF SECOND OR THIRD FLOORS

simple building plan. The local building inspector can help you calculate building areas.

Step II: Calculate Actual AEI

The definition of the AEI of a building is the total energy consumed annually in the building per square foot of building area, and is expressed in units of MBTU's per square foot. Since the amount of energy contained in each type of fuel differs, the conversion factors in Table I-1 are given to be used in calculating the total energy in any quantity of each of the fuels most commonly used in buildings.

Use Worksheet 2 to calculate the AEI of a building. Copies of this worksheet should be made for each municipal building.

The following example shows a step-by-step method for calculating the AEI of a building; in this case, the building is the typical school described in Sample Worksheet 1).

Example I-1: AEI Calculations

Building data from Worksheet 1: (see Sample Worksheet 1)

building type: school built after 1945	
KWH of electricity consumed:	242,000 KWH
gallons of #2 oil consumed:	49,334 gallons
CCF of natural gas consumed:	0 CCF
total energy cost:	$ 31,800
building area:	50,120 square feet

Result: Actual AEI = 202.6 (see Sample Worksheet 2)

TABLE I-1

ENERGY CONVERSION FACTORS FOR
COMMON ENERGY SOURCES FOR BUILDINGS

Energy Source	Units of Measure	Conversion Factors
Electricity	KWH	11.38
#2 Oil	Gallons	139.0
#4 Oil	Gallons	150.0
#5 Oil	Gallons	152.0
#6 Oil	Gallons	153.0
Natural Gas	CCF (hundred cubic feet)	103.1

SAMPLE WORKSHEET 2

ANNUAL EFFICIENCY INDEX (AEI) WORKSHEET

1. FILL IN THE TOTAL QUANTIES OF FUEL IN THE APPROPRIATE SQUARES ON THE WORK SHEET.
2. MULTIPLY THE TOTAL KWH OF ELECTRICITY CONSUMED TIMES THE CONVERSION FACTOR: 242,000 (total KWH) x 11.38 = 2,753,960 MBTU's
3. MULTIPLY THE TOTAL GALLONS OF #2 OIL CONSUMED TIMES THE CONVERSION FACTOR: ______ (total gallons) x 139.00 = 0 MBTU's
4. MULTIPLY THE TOTAL GALLONS OF #4 OIL CONSUMED TIMES THE CONVERSION FACTOR: 49,334 (total gallons) x 150.00 = 7,400,100 MBTU's
5. MULTIPLY THE TOTAL GALLONS OF #5 OIL CONSUMED TIMES THE CONVERSION FACTOR: ______ (total gallons) x 152.00 = 0 MBTU's
6. MULTIPLY THE TOTAL GALLONS OF #6 OIL CONSUMED TIMES THE CONVERSION FACTOR: ______ (total gallons) x 153.00 = 0 MBTU's
7. MULTIPLY THE TOTAL CCF OF NATURAL GAS CONSUMED TIMES THE CONVERSION FACTOR: ______ (total CCF) x 103.10 = 0 MBTU's
8. ADD UP THESE MBTU'S TO GET THE TOTAL BUILDING ENERGY CONSUMPTION: TOTAL ENERGY 10,154,060 MBTU's
9. ENTER THE TOTAL ENCLOSED AREA OF THE BUILDING HERE: AREA 50,120 SQ. FT.
10. DIVIDE THE TOTAL ENERGY (LINE 8) BY THE AREA (LINE 9) TO GET THE BUILDING AEI: AEI 202.6 MBTU's/SQ. FT.

<u>Step III: Compute Standard AEI</u>

It is not accurate to suggest that the same Standard AEI's should be applied in all areas of Massachusetts. A building in a more severe climate will consume more energy per square foot than a similar building in a milder climate. Municipalities on Cape Cod, the North and South Shores, and along the southern coast do not experience the severe winters that towns in Western and Central Massachusetts do.

The Standard AEI must be adjusted annually in your area. Table I-2 lists climatic adjustment factors for fifty locations around the state. These adjustments are given for the five most recent fiscal years, thereby taking into account the variation in climate due to both geographic location and the relative severity of the winters in each location from year to year.

To use Table I-2, pick the location nearest your own, then pick the fiscal year for which you have consumption data and find the adjustment factor in the table. Multiply the Standard AEI's in Worksheet 3 by the adjustment factor you have just found in Table I-2. The following example demonstrates the entire process of climatic adjustment.

TABLE I-2 CLIMATIC ADJUSTMENT FACTORS FOR MASSACHUSETTS

STATION	1975/76	1974/75	1973/74	1972/73	1971/72
Adams	1.30	1.32	1.27	1.28	1.31
Borden Brook Res.	1.29	1.36	NA	1.38	1.37
Chester	1.27	1.31	1.21	1.27	1.35
Cunningham Hill	1.31	1.37	1.34	1.36	1.37
Great Barrington	1.29	1.36	1.28	NA	NA
Hoosac Tunnel	NA	NA	NA	1.30	1.32
Knightsville Dam	1.27	1.30	1.32	1.27	1.32
Lanesboro	1.39	1.44	NA	1.42	1.43
Stockbridge	NA	1.29	1.25	1.26	1.32
Amherst	1.09	1.15	1.13	1.11	1.15
Barre Falls Dam	1.32	1.37	1.34	1.33	1.38
Bedford	1.09	1.12	1.11	1.13	1.17
Birch Hill Dam	1.35	1.40	1.33	1.34	1.41
Blue Hill	1.05	1.12	1.10	1.11	1.15
Buffumville Dam	1.20	1.27	1.21	1.20	1.24
Chestnut Hill	NA	NA	0.93	NA	1.10
Clinton	1.06	1.20	1.22	1.19	1.24
Dracut	1.17	1.22	1.22	1.22	1.22
Dunstable	1.14	1.19	1.15	1.19	1.21
East Brimfield Dam	1.18	1.23	1.20	1.18	1.25
Fitchburg	NA	1.16	1.14	1.16	1.19
Framingham	1.03	NA	1.06	NA	NA
Haverhill	1.01	1.05	1.02	1.07	1.09
Lawrence	1.06	1.11	1.10	1.10	1.13
Reading	1.10	1.16	1.13	1.14	1.18
Shelburn Falls	1.25	1.27	1.24	1.27	1.31
Springfield	1.00	1.06	1.02	1.04	1.09
Tully Dam	1.30	1.34	1.28	1.31	1.34
Turner Falls	1.14	1.18	1.15	1.16	1.21
Walpole	1.03	1.10	1.06	NA	NA
West Medway	1.13	1.18	1.14	1.13	1.18
Worcester	1.18	1.23	1.19	1.23	1.23
Boston	0.87	0.98	0.96	1.00	0.98
Brockton	1.03	1.11	1.07	1.05	1.12
South Wellfleet	0.94	1.02	NA	1.00	1.03
Chatham	0.97	1.03	1.01	NA	NA
East Wareham	1.06	1.07	1.07	1.05	1.09
Edgartown	0.94	1.00	1.00	0.99	1.02
Fall River	NA	1.02	0.99	1.00	1.03
Hingham	1.00	1.07	1.02	1.04	1.08
Middleton	1.01	1.08	1.05	1.07	1.10
Nantucket	0.94	1.03	1.10	1.09	1.01
New Bedford	NA	0.80	NA	0.86	0.91
Peabody	1.04	1.10	1.07	1.11	1.13
Plymouth	1.05	1.14	1.10	1.08	1.14
Provincetown	NA	1.02	1.01	NA	NA
Rochester	1.05	1.09	1.11	1.10	1.13
Rockport	1.02	1.09	1.06	1.08	1.11
Taunton	1.06	1.14	1.12	1.10	1.14

Example I-2: How to Adjust Standard AEI's for Local Climates

Assume Standard AEI's are to be adjusted for the climate of Lowell, MA during the 74/75 fiscal year.

Step 1: Locate Lowell in Table I-2. (Since no value is given for Lowell, take the value for Lawrence which is nearby.)

Step 2: Under the year of fiscal 74/75 in Table I-2, the adjustment factor 1.11 is found.

Step 3: Using the space provided in Worksheet 3, multiply each Base Standard AEI by 1.11 to find the adjusted Standard AEI for Lowell.

Climatic Adjustments for Future Years

Table I-2 contains climatic adjustment factors for the fiscal years up to and including 1975-76. Since it will be necessary to have updated climatic adjustment factors each year, two methods are provided to enable local personnel to determine these factors for themselves.

- *METHOD 1: Averaging*

  Although the climate varies somewhat from year to year in a given location, it is possible to base future local standards on an average of the five factors shown in Table I-2. This is not the most accurate method, but it is sufficient to use in formulating base-year standards.

  Example:

  For Clinton, the average climatic factor from Table I-2 would be calculated as follows:

$$\text{Average Climatic Adjustment Factor} = \frac{1.06 + 1.20 + 1.22 + 1.19 + 1.24}{5} = 1.18$$

- *METHOD 2: Accurate Calculation*

  The true value of climatic adjustment factors for future years can be easily calculated from published weather data. Weather data for New England is published each month by the National Oceanographic and Atmospheric Administration (NOAA). In each year's July publication, the reader will find a table of "Monthly and Seasonal Heating Degree Days" for locations in Massachusetts. The total heating degree days of each location in this table forms the basis of the climatic adjustment factor.

  The new factor is determined by dividing the total local heating degree days by 5621.

SAMPLE WORKSHEET 3

BUILDING TYPE	BASE AEI STANDARD* (MBTU'S/SQ.FT.)	CLIMATIC ADJUSTMENT FACTOR**	LOCAL AEI STANDARD (MBTU'S/SQ.FT.)
SCHOOLS BUILT BEFORE 1945	105	x 1.11 =	117
SCHOOLS BUILT AFTER 1945	120	x 1.11 =	133
FIRE STATIONS	135	x 1.11 =	150
TOWN HALLS (OFFICES)	115	x 1.11 =	128
LIBRARIES	110	x 1.11 =	122
POLICE STATIONS	105	x 1.11 =	117
DPW GARAGES	105	x 1.11 =	117

*BASE STANDARDS ARE BASED UPON AN ANNUAL HEATING SEASON OF 5621 DEGREE DAYS (BOSTON'S 30 YEAR NORMAL)

**CLIMATIC ADJUSTMENT FACTORS FOR FIFTY LOCATIONS IN MASSACHUSETTS ARE GIVEN IN TABLE 3.

SAMPLE WORKSHEET 4

POTENTIAL ENERGY SAVINGS

1. ENTER ACTUAL AEI FROM WORKSHEET 2 AND STANDARD AEI FROM WORKSHEET 3 BELOW.

2. COMPUTE THE ENERGY SAVINGS FACTOR.

   (202.6 — 133) ÷ 202.6 = $\boxed{.35}$

   (Actual AEI — Standard AEI) ÷ Actual AEI = Energy Savings Factor

3. ENTER THE TOTAL ANNUAL ENERGY COST FROM WORKSHEET 1 BELOW.

4. COMPUTE THE POTENTIAL ANNUAL SAVINGS.

   ($31,800) x (.35) $\boxed{\$11,027}$

   (Annual Energy Cost) X (Energy-Savings Factor) Potential Annual Savings

Example:

In the July 1978 publication of *Climatological Data for New England*, the total heating degree days for Clinton, MA might be listed as 6500.

The 1977/78 climatic adjustment factor for Clinton would be:

$$\text{77/78 Climatic Adjustment Factor} = \frac{6500}{5621} = 1.16$$

To obtain this information from NOAA, send orders for the July issue of *Climatological Data for New England* to:

National Climatic Center
Federal Building
Asheville, NC 28801

Attention: Publications

The current price of the July issue is 35¢.

Step IV: Determine Potential Energy Savings

Once actual and locally adjusted Standard AEI's are known, it is possible to determine the potential energy savings in a building as a percentage of its current annual consumption. Use copies of Worksheet 4 to calculate the potential energy savings in each municipal building.

Example I-3:

Assume that the school used in Example I-1 is located in Lowell. Using the local Standard AEI's for 74/75 from Example I-2, calculate the potential annual savings for the school.

Data from Worksheets:

Actual AEI	202.6	(from Worksheet 2)
Standard AEI	133	(from Worksheet 3)
Annual Energy Cost	$ 31,800	(from Worksheet 1)

Result: Potential Annual Savings = $11,027.00 (see Sample Worksheet 4).

When the potential savings for each municipal building are known, departmental and municipal potentials can be evaluated using Worksheet 5. In ensuing years, these potentials should shrink as actual energy consumption is reduced to or below the local consumption standards. This would indicate a successfully conducted energy management program.

FUEL CONSUMPTION DATA WORKSHEET

MUNICIPALITY: ______________________

BUILDING NAME: ______________________

FISCAL YEAR: ______________________

BUILDING AREA: ______________________

TOTAL ANNUAL ENERGY COST: ____________

TOTAL ANNUAL ENERGY CONSUMPTION (MBTU'S): ____________

MONTH/YEAR	NATURAL GAS CONSUMED (CCF)	NATURAL GAS COST (DOLLARS)	# OIL CONSUMED (GALLONS)	# OIL COST (DOLLARS)	# OIL CONSUMED (GALLONS)	# OIL COST (DOLLARS)	ELECTRICITY CONSUMED (KWH)	ELECTRICITY COST (DOLLARS)
JUNE								
JULY								
AUG								
SEPT								
OCT								
NOV								
DEC								
JAN								
FEB								
MAR								
APR								
MAY								
TOTALS:								

WORKSHEET I

WORKSHEET 2

ANNUAL EFFICIENCY INDEX (AEI) WORKSHEET

1. FILL IN THE TOTAL QUANTIES OF FUEL IN THE APPROPRIATE SQUARES ON THE WORK SHEET.
2. MULTIPLY THE TOTAL KWH OF ELECTRICITY CONSUMED TIMES THE CONVERSION FACTOR: ________ (*total KWH*) x 11.38 = [ ] MBTU's
3. MULTIPLY THE TOTAL GALLONS OF #2 OIL CONSUMED TIMES THE CONVERSION FACTOR: ________ (*total gallons*) x 139.00 = [ ] MBTU's
4. MULTIPLY THE TOTAL GALLONS OF #4 OIL CONSUMED TIMES THE CONVERSION FACTOR: ________ (*total gallons*) x 150.00 = [ ] MBTU's
5. MULTIPLY THE TOTAL GALLONS OF #5 OIL CONSUMED TIMES THE CONVERSION FACTOR: ________ (*total gallons*) x 152.00 = [ ] MBTU's
6. MULTIPLY THE TOTAL GALLONS OF #6 OIL CONSUMED TIMES THE CONVERSION FACTOR: ________ (*total gallons*) x 153.00 = [ ] MBTU's
7. MULTIPLY THE TOTAL CCF OF NATURAL GAS CONSUMED TIMES THE CONVERSION FACTOR: ________ (*total CCF*) x 103.10 = [ ] MBTU's
8. ADD UP THESE MBTU'S TO GET THE TOTAL BUILDING ENERGY CONSUMPTION: *TOTAL ENERGY* [ ] MBTU's
9. ENTER THE TOTAL ENCLOSED AREA OF THE BUILDING HERE: *AREA* [ ] SQ. FT.
10. DIVIDE THE *TOTAL ENERGY* (LINE 8) BY THE *AREA* (LINE 9) TO GET THE BUILDING AEI: *AEI* [ ] MBTU's/SQ. FT.

WORKSHEET 3

BUILDING TYPE	BASE AEI STANDARD* (MBTU'S/SQ.FT.)	CLIMATIC ADJUSTMENT FACTOR**	LOCAL AEI STANDARD (MBTU'S/SQ.FT.)
SCHOOLS BUILT BEFORE 1945	105	x ☐ =	______
SCHOOLS BUILT AFTER 1945	120	x ☐ =	______
FIRE STATIONS	135	x ☐ =	______
TOWN HALLS (OFFICES)	115	x ☐ =	______
LIBRARIES	110	x ☐ =	______
POLICE STATIONS	105	x ☐ =	______
DPW GARAGES	105	x ☐ =	______

*BASE STANDARDS ARE BASED UPON AN ANNUAL HEATING SEASON OF 5621 DEGREE DAYS (BOSTON'S 30 YEAR NORMAL)

**CLIMATIC ADJUSTMENT FACTORS FOR FIFTY LOCATIONS IN MASSACHUSETTS ARE GIVEN IN TABLE 3.

WORKSHEET 4

POTENTIAL ENERGY SAVINGS

1. ENTER ACTUAL AEI FROM WORKSHEET 2 AND STANDARD AEI FROM WORKSHEET 3 BELOW.

2. COMPUTE THE ENERGY SAVINGS FACTOR.

   (________ — ________) ÷ ________ = $\boxed{}$

   (Actual AEI — Standard AEI) ÷ Actual AEI = Energy Savings Factor

3. ENTER THE TOTAL ANNUAL ENERGY COST FROM WORKSHEET 1 BELOW.

4. COMPUTE THE POTENTIAL ANNUAL SAVINGS.

   (__________) X (__________) $\boxed{}$

   (Annual Energy Cost) X (Energy-Savings Factor) Potential Annual Savings

WORKSHEET 5

MUNICIPAL BUILDING ENERGY SAVINGS POTENTIAL

MUNICIPALITY: ____________________

FISCAL YEAR: __________

DEPARTMENTAL SUB-TOTALS.

DEPARTMENT	BUILDING NAME	ANNUAL MBTU'S CONSUMED[1]	SAVINGS FACTOR[2]	ANNUAL ENERGY COST[2]	POTENTIAL SAVINGS[2]	TOTAL ENERGY COST	TOTAL POTENTIAL SAVINGS	AVERAGE SAVINGS/ BUILDING
				$	$	$	$	$

[1] From WORKSHEET 2 [2] From WORKSHEET 4

GENERAL PRINCIPLES AND THE MOST EFFECTIVE PRACTICES FOR SAVING ENERGY IN MUNICIPAL BUILDINGS

A building audit or evaluation of the energy savings potential of a given building is likely to identify a large number of possible measures that might be implemented. Some of these will have a relatively greater effect than others. The intent of this section is to convey to supervisory and operating personnel who may not have extensive technical training a conceptual understanding of the reasons selected conservation measures were found to be particularly effective in municipal buildings.

To meet this need, this section begins with a brief illustrated discussion of the basic principles of how energy is used in buildings. These principles provide a framework for discussing eighteen specific conservation measures that are particularly appropriate to municipal buildings. Each measure is analyzed in terms of how it works and an estimate of the relative savings and costs that might be expected is made. To provide a more concrete context for the discussion, examples of the application of measures in new schools and old schools are used. These should be understood as examples that apply to two general building types, older brick and mortar construction and newer mechanically ventilated buildings, not to schools alone.

At the close of the discussion, these measures are listed by the type of municipal building in which they are most likely to be effective.

General Principles that Determine the Demand for Heating in Municipal Buildings

Transmission

Whenever a difference in air temperature exists between a building interior and the outdoor climate, energy is transmitted by the materials in the walls, floor, and roof from the warmer to the colder environment through a continuous and irreversible process. This process is referred to as heat transmission. During the heating season, when the interior of a building must be substantially warmer than the cold outdoor air, the energy transmitted out of the building must be replaced by heating energy supplied by the consumption of fossil fuel or electrical energy.

Infiltration

Another process through which energy loss occurs involves the introduction of cold outside air into interior space, forcing the warm air out of the building and lowering the indoor temperature. The effect of this process is similar to that of adding ice cubes to a pan of water being heated to a boil. The cooling effect of the ice lengthens the boiling process and consumes much more energy than would have been required to boil the water without the addition of ice cubes.

In a building, cold outside air is introduced to the interior in three ways:

1. Structural Infiltration: Air seeps through unavoidable cracks around windows, doors, and in the structure of the building;
2. Opened Doors and Windows: Whenever a door or window is opened, a large volume of cold air flows into the building; and
3. Forced Ventilation: In certain types of buildings, health codes require that outdoor air be introduced into the interior at a fixed rate. In these buildings, outdoor air is drawn in by a mechanical ventilating system that must operate whenever the buildings are fully occupied.

System Inefficiencies

The last major process of heat loss involves the combustion of fossil fuel in the building heating system. For buildings with oil or gas heating systems, fossil fuel is burned in the presence of oxygen, releasing heat in the form of hot gases. These gases flow through some type of heat exchanger, which captures the largest portion of the heat content of the gases for circulation within the building. The residual heat in the gases flows up a stack and is exhausted.

The combustion gases that are exhausted have temperatures in excess of 500 degrees, and between a quarter and a third of the energy contained in the original fuel is lost. This heat loss is termed the *stack loss*. At peak efficiency (seasonal efficiency), a gas or oil burner can only deliver approximately 75% of the energy contained in the fuel to the building in the form of usable heat. If the boilers are oversized or the burners are improperly adjusted, the actual efficiency can be much lower.

In an all-electric building, the heating efficiency can be as high as 100%. This is to say that all of the energy delivered to the building may be converted to usable heat. However, the generation of electricity is in itself subject to the inefficiencies of fossil fuel combustion. Under the best conditions, three barrels of oil are required to generate an amount of electricity which has an energy value equivalent of one barrel of oil. The heat content from two of every three barrels of oil is lost at the generating plant.

Since the price of electricity reflects the costs of the oil consumed in generation, the equivalent "stack losses" of an all-electric building exceed 65% of the available fossil fuel energy. If the

original fossil fuel consumption is considered, rather than the electricity by-product, an all-electric school has a "combustion-efficiency" of 35% at best. This compares with a peak seasonal combustion-efficiency of 75% for a gas or oil heating system.

The effects of heat transmission, infiltration/ventilation, and combustion stack losses are additive and, when combined, represent most of the total heat losses of a building.

Internal Heat Gains

Aside from the heat supplied by the combustion of fossil fuels, buildings gain some heat from other sources. The occupants of a building add a surprising amount of heat to the interior space. An inactive, seated adult adds 450 BTU/hour to the surrounding environment. At this rate, the heat supplied by 222 seated adults in an hour is equivalent to the heat that would be supplied by 1 gallon of oil at 70% efficiency.

In schools with a large student population, the demand for oil during occupied periods is significantly reduced by the heat supplied by the occupants. On the other hand, when these buildings are not fully occupied the demands upon the heating system are greater.

The lights and electrical equipment in a building also contribute heat to the interior space, since all of the electrical energy consumed by these devices is eventually emitted as heat. In new buildings, the lighting system usually consumes in the range of 2 to 4 watts/square foot. This translates to a heat gain of 7 to 14 BTU's per square foot per hour, which in a 60,000 square foot school is the equivalent to the heat supplied from 4.2 to 8.4 gallons of oil per hour.

The third important source of heat gain is the sun. During a sunny day, solar gains may reach a peak equivalent to 3.5 gallons of oil per hour, although the average hourly contribution is closer to one gallon per hour.

The magnitude of the solar gains in a building depends upon building orientation, the amount of window area, and of course the availability of sunlight. It should be noted, however, that in the evenings heat loss through windows is substantial and may in fact exceed the solar gains made during the day. It is important that this trade-off be remembered, especially when a building is designed.

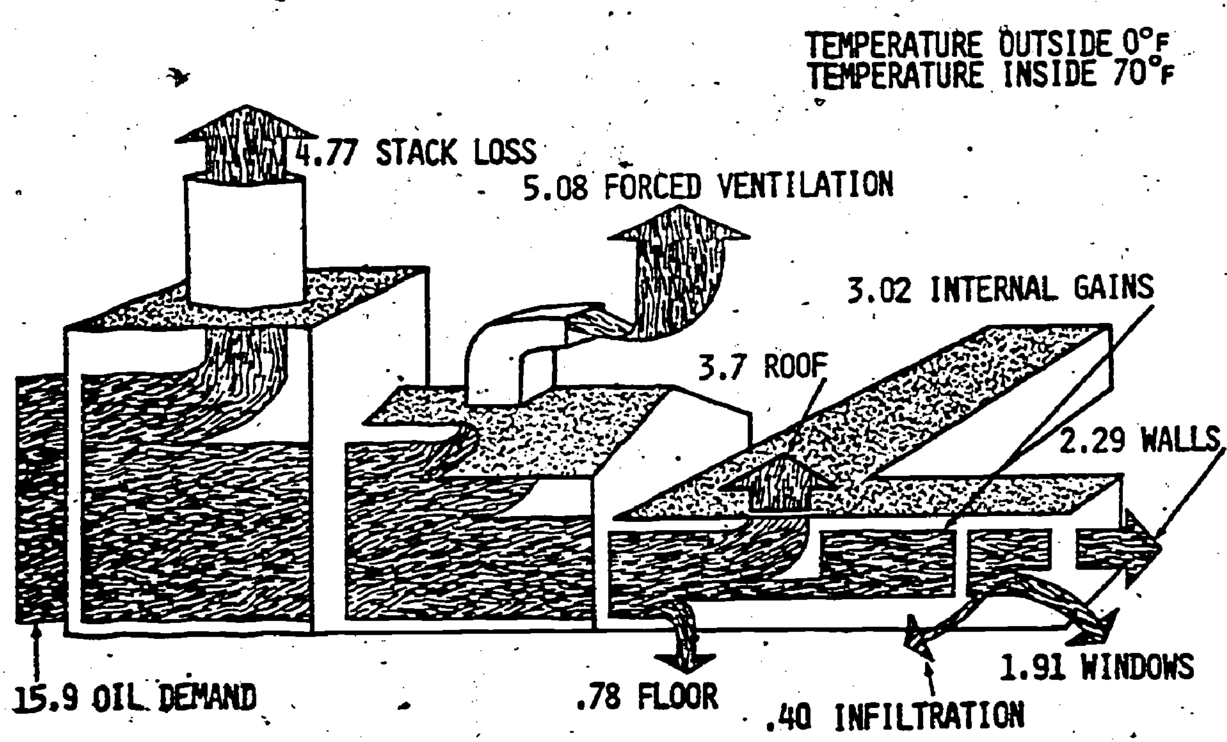
The Energy Balance

The rate at which energy is consumed to heat a building is governed directly by the rate of energy loss from the building. This is the concept of the "energy balance," which may be expressed simply as follows:

Heat Required = Heat Lost

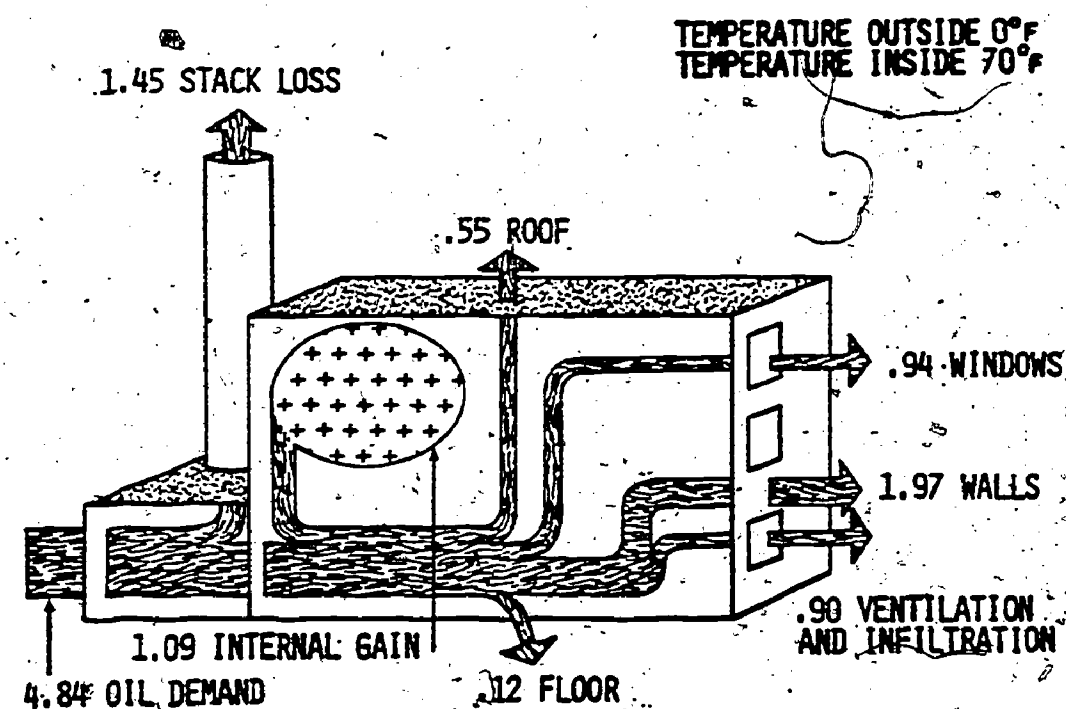
To illustrate the concept, Figures II-1 - II-4 indicate schematically the components of the heat loss from two school buildings under two different outdoor temperatures. Figures II-1 and II-3 represent a

FIGURE II-1 1956 SCHOOL AREA = 34,400 SQUARE FEET



NUMBERS REFER TO GALLONS OF OIL PER HOUR

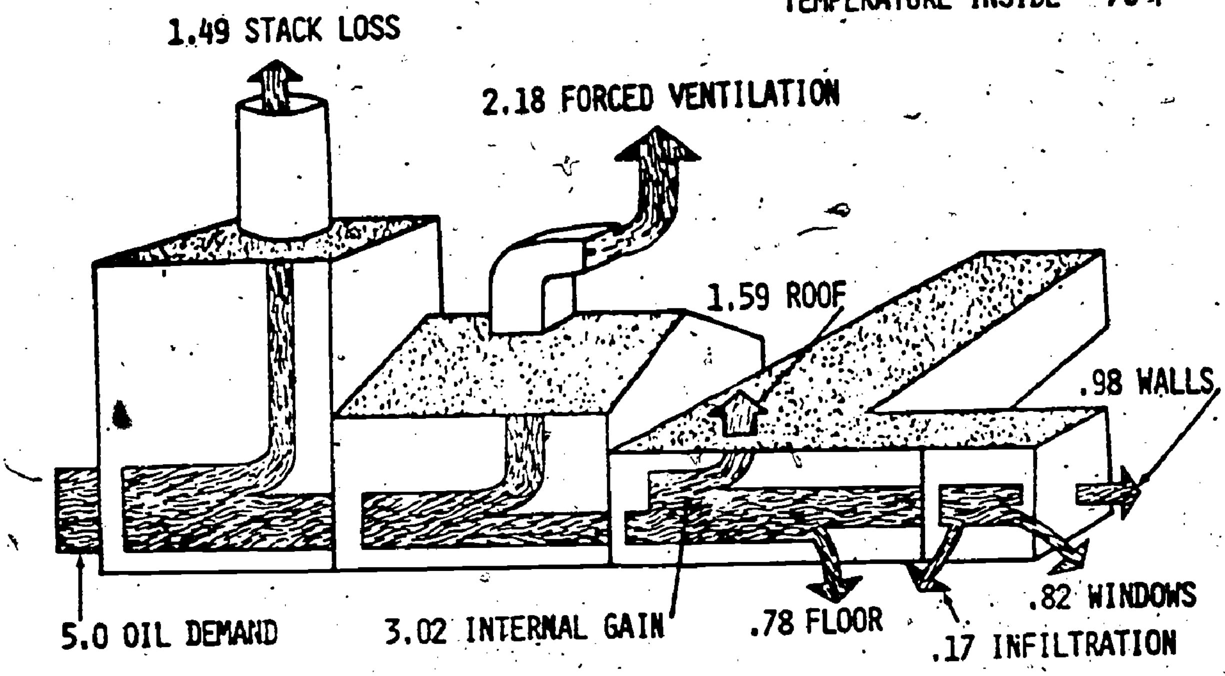
FIGURE II-2 1892 SCHOOL AREA = 16,000 SQUARE FEET



NUMBERS REFER TO GALLONS OF OIL PER HOUR

FIGURE II-3 1956 SCHOOL AREA = 34,400 SQUARE FEET

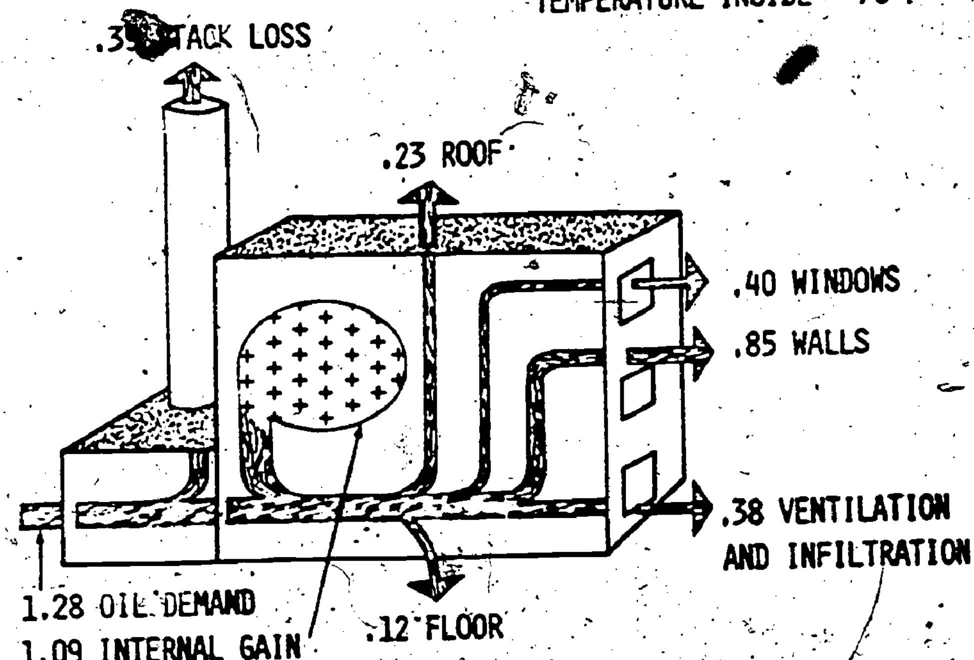
TEMPERATURE OUTSIDE = 40°F
TEMPERATURE INSIDE = 70°F



NUMBERS REFER TO GALLONS OF OIL PER HOUR

FIGURE II-4 1892 SCHOOL AREA = 16,000 SQUARE FEET

TEMPERATURE OUTSIDE = 40°F
TEMPERATURE INSIDE = 70°F



NUMBERS REFER TO GALLONS OF OIL PER HOUR

typical post-1945 school building with a student population of 600, while Figures II-2 and II-4 represent a typical pre-1945 school with 180 students. In Figures II-1 and II-2, the heat losses from each building are shown for an indoor temperature of 70 degrees and an outdoor temperature of 0 degrees. The energy loss is expressed in terms of gallons of oil per hour.

In Figure II-1 it can be seen that, under the temperatures shown, 8.68 gallons of oil per hour are lost by heat transmission through walls, windows, roof, and floor, 5.48 gallons per hour are lost through forced ventilation and infiltration of outdoor air, and 4.77 gallons per hour are lost up the stack. In sum, 18.93 gallons of oil are lost per hour under the temperatures shown.

Offsetting this loss are the 3.02 gallons per hour in heat released by the building occupants and the interior lighting and the 15.91 gallons of oil actually consumed (solar gains are not included).

For the pre-1945 school under the same temperature conditions (Figure II-2), 3.58 gallons per hour are lost through transmission, 0.90 gallons per hour through ventilation and infiltration, and 1.45 gallons per hour are lost up the stack. The total heat lost per hour (5.93 gallons of oil) is offset by 1.09 gallons per hour in internal gains and 4.84 actual gallons of oil.

Since the buildings in the example are based on the typical scale of schools evaluated in the ECP study, the building in Figure II-2 has only half the floor area of the more modern building in Figure II-1. While these buildings are of typical size, it can be shown that a pre-1945 school as shown in Figure II-2, with a floor area equivalent to that of the modern school, would require 5.21 gallons of actual oil under the same temperature conditions.

In Figures II-3 and II-4, the same buildings are shown under a milder outdoor temperature condition (40 degrees). Notice the reduction in the demand for oil for each building. For the 1956 school (Figures II-1 and II-3), only 5 gallons per hour are needed when the outdoor temperature is 40 degrees, as opposed to the 15.9 gallons per hour needed at 0 degrees. In the 1892 school (Figures II-2 and II-4), the reduction is from 4.84 to 1.28 gallons per hour.

Most of the components of the heat loss vary directly with the difference in the interior and exterior temperatures (called Δt). In Figures II-1 and II-2 the Δt is 70 degrees (70 - 0), and in Figures II-3 and II-4 the Δt is 30 degrees (70 - 40). The internal heat gain does not vary with Δt, but depends instead upon the number of occupants and the power consumed for lighting and equipment. The transmission losses through the floor also remain about the same because the temperature of the earth remains fairly constant during the heating season.

Effective Measures for Conserving Energy in Municipal Buildings

The major opportunities for significantly reducing the energy consumption of municipal buildings depend upon procedures that reduce the

rate of heat loss from buildings during the heating season. (Energy conservation through reduced lighting is discussed separately.) More specifically, any measure that reduces heat transmission; reduces ventilation and infiltration; reduces heating system inefficiencies; or reduces the difference in indoor and outdoor temperatures will result in significant energy savings without sacrificing the comfort or convenience of the building's occupants.

It should be remembered that a particular energy conservation measure will have varying effects in different types of buildings. The intent of this section is to suggest the potential savings of proven measures for the types of building where they are likely to have the greatest impact. Furthermore, not all measures have an additive effect on the total energy consumption of a building. In the discussion of a measure, the savings opportunities described are for that one measure alone. The total savings from several measures may be less than the sum of each when considered separately.

Measures that Reduce the Difference in Indoor and Outdoor Temperatures

The magnitude of the difference between the air temperature inside and outside a building directly affects the rate of fuel consumption.

A comparison between Figures II-1 and II-3, or between Figures II-2 and II-4, demonstrates this effect. These figures show that by reducing the temperature difference from 70 to 30 degrees the hourly energy consumption is reduced by two-thirds in one building and by three-quarters in the other.

While this example concerns a change in outdoor temperatures, a change of the same magnitude in indoor temperatures would have the same effect on the consumption of oil.

If the outdoor temperature is a constant 0 degrees and the indoor temperature is lowered 40 degrees (from 70 to 30 degrees), the resulting reduction in the energy demand is exactly the same as that shown in the example. While 30 degrees is not a practical indoor temperature setting—even during unoccupied periods—a more modest reduction is practical. A temperature set-back to 55 degrees during unoccupied periods would save 4.1 gallons of oil per hour in the school shown in Figure II-1 (at 0 degrees outside).

The important principle to remember is this: It is not the indoor or outdoor temperature alone that determines the rate of fuel consumption, but rather the difference in those temperatures. The greater the difference, the higher the rate of fuel consumption.

- *MEASURE 1: Reduce the indoor temperature to 55 degrees F during unoccupied periods (night and weekend set-back).*

  Guidelines for Implementing the Measure:

  Night set-back requires that either an assigned person (the building operator) or an automatic timing device turn down the thermostats every afternoon to 55 degrees and

turn them back up early in the morning. The actual time of day for altering the settings will depend upon the season and the severity of the weather on particular days. The operator should proceed on a trial and error basis to determine how long it takes for the building to heat up in the morning and cool off in the afternoon.

Once a "feel" for these time lags is established, the operator should aim to have the building reach 68 degrees about 30 minutes after the occupants arrive and should probably set back the temperature 30 minutes to an hour prior to the closing of the building.

In newer buildings (particularly schools), time clocks are often provided that automatically control night set-back. The operators only have to choose the proper settings for set-back to occur.

Potential Annual Savings:

The level of savings depends upon the building construction, the number of degrees that thermostats are set back, and the number of hours that set-back is maintained. However, savings of 35 to 50% of the annual heating energy are possible in some buildings.

Implementation Cost

In most cases, this measure has no implementation cost.

- *MEASURE 2: Reduce indoor temperature during occupied periods to 65° F during the heating season.*

Guidelines for Implementation:

An indoor temperature of 65° F is adequate for the physical comfort of most people. Others will find it necessary to dress more warmly.

For this measure to succeed, thermostatic temperatures must be monitored carefully to ensure that a setting of 65° F is maintained.

Potential Annual Savings:

Assuming an original thermostat setting of 70° F, a reduction to 65° F will reduce the annual fuel consumption for heating by approximately 4%.

Implementation Cost:

None.

- *MEASURE 3: Install adequate thermostatic controls on heating systems.*

Guidelines for Implementation:

Some of the older municipal buildings waste energy because they lack adequate controls for the heating system. Often a town hall or old school will have only one thermostat

per floor, resulting in an over- or under-supply of heating in rooms that are more removed from the location of the thermostat. Although one might postulate that these extremes tend to cancel each other so that the total energy consumption is unchanged, this is rarely the case.

In fact, the thermostats are more likely to be set high enough to keep the cold rooms comfortable. Then, as the overheated rooms become even hotter, the occupants often open windows to balance the excessive heating. Thus heat energy is literally pumped out of the open windows. Buildings should be equipped with additional thermostats whenever the existing controls are unable to maintain near-constant temperatures throughout the heating zones they are designed to monitor. At a minimum, every floor should have a separate thermostat; ideally, every room should have a thermostat.

Potential Savings:

Cost/benefit studies of this measure were conducted by R. G. Vanderweil Engineers, Inc. in two older schools in the ECP Demonstration (Studies 1 and 2). These studies show that the potential savings depend upon the number of rooms that are normally overheated and the number of degrees the temperature is maintained in excess of the thermostatic setting. The higher Δt's in these areas result in higher rates of heat loss to the outside. Savings of 14% are possible in some buildings.

Implementation Cost:

The cost of this measure includes the installation of thermostats and additional valves in the heating system. In the ECP Demonstration studies, these costs were returned in energy savings within 1 - 3 years.

Measures that Reduce Heating System Inefficiencies

The production of usable heat for buildings from the combustion of a fossil fuel is subject to substantial losses in efficiency. On an annual basis, the usable heat produced by a heating system is at most around 75% of the total heat value of the fuel that is consumed.

A properly adjusted boiler operates most efficiently when the total hourly heat loss of the building is near the maximum output of the system. This condition is referred to as the "full load" of the burner-boiler. At full load, the heating system can convert up to 90% of the energy of the fuel into usable heat. However, full loading only occurs during 2% of the heating season.

When the demands on the heating system are significantly less than its capacity, the system operates more and more sporadically, and as a result its efficiency falls. During 90% of the heating season the typical burner-boiler operates less than 14 hours a day and utilizes as little as 65% of the available energy in the fuel. Of course, if

the burners are improperly adjusted and maintained—as they are in many cases—even greater amounts of energy are wasted.

- *MEASURE 4: Measure the burner-boiler efficiency and adjust to achieve maximum efficiency.*

  Guidelines for Implementation:

  It is a relatively simple process to measure the instantaneous burner-boiler efficiency. Generally, the oil supplier will make the measurements and the necessary adjustment, although local personnel can be trained to perform these tasks. Measurements should be made at least once per year in each building.

  Potential Annual Savings:

  Any improvement in the seasonal efficiency of a heat system will result in a proportionate reduction in energy consumption. A 7% improvement in seasonal efficiency will save at least 7% in annual fuel consumption.

  Implementation Cost:

  Oil suppliers generally provide this service at no cost. If not, the cost should be less than $50 per building.

- *MEASURE 5: For buildings used in the summer, install a separate domestic hot water heater.*

  Guidelines for Implementation:

  In a number of fire stations and in a few schools in Massachusetts, it is not uncommon to find the heating system operating during the summer months to provide domestic hot water. The demand for domestic hot water is fairly constant year-round (in buildings with year-round occupancy), but is only a small proportion of the full output of the heating system in the summer. Because the heating system must supply only a fraction of its maximum output, its efficiency is quite low. A separate small domestic hot water heater should be installed and the larger heating system should be completely shut down during the summer.

  Potential Savings:

  The potential savings in a typical fire station for this measure were estimated at $96/year by R. G. Vanderweil Engineers, Inc. (Refer to Study 3.)

  Implementation Cost:

  The cost of a separate hot water heater in the same fire station was estimated at $240, leading to a payback period of 2.5 years.

- *MEASURE 6: Improve heating system efficiency by heat recovery from the boiler stack.*

Guidelines for Implementation:

Even when the boiler-burner of a building heating system is adjusted to peak efficiency, at least 25% of the heating value of the fuel consumed annually is lost up the stack. Some of this waste heat can be saved through the use of a heat recovery device. R. G. Vanderweil Engineers, Inc. studied two applications of a system for heat recovery from boiler stacks in ECM Demonstration municipalities.

These applications involved the use of a piping system running between the inside of the boiler stack and the water tank portion of the boiler. Water is circulated through this piping and is heated by the exhausted flue gases. This hot water transfers heat to the boiler water, preheating it so that less energy is required from the burning of fuel to maintain the required boiler water temperature.

Potential Annual Savings:

The estimated savings from this type of heat recovery system for two Massachusetts schools are detailed by Vanderweil Engineers in cost/benefit studies (Studies 4 and 5). Generally, annual savings of 8 - 9% of the heating energy can be expected in many buildings.

Implementation Costs:

The costs of these systems vary with each building, since they must be tailored to fit into existing heating systems. The costs in the two demonstration applications are analyzed in the studies.

- *MEASURE 7: Improve heating system efficiency by heat recovery from exhausted air.*

Guidelines for Implementation:

In many buildings or sections of buildings (especially new schools), a substantial amount of heat is exhausted from the building by the ventilation system. Under certain conditions, part of this heat can be saved by a heat recovery device called a "thermal wheel." The thermal wheel rotates slowly through an exhaust duct and an adjacent supply duct. The wheel allows each air stream to flow through its surface much like a breeze passes through a screen. The wheel is warmed by the exhaust air stream and, as it rotates, it transfers heat into the cold incoming supply air. Since the supply air is warmed several degrees by the thermal wheel, less energy is needed to heat it up to room temperature.

The feasibility of a thermal wheel is governed by the ventilation rate and the layout of the supply and exhaust air ducts in the building. One area that is often parti-

cularly suited for a thermal wheel is an indoor swimming pool, where the ventilation rate and the indoor air temperature are usually quite high. This particular application was studied by R. G. Vanderweil for the indoor pool of a high school in one of the demonstration municipalities.

Potential Savings:

Generally, where the installation of thermal wheels is practical, 60% to 80% of the heat in the exhaust air can be recovered by the wheel. See the Vanderweil study (Study 6) for a specific example.

Implementation Cost:

The costs of a thermal wheel installation depends upon the ventilation rate and the amount of ductwork alteration that is required. Excluding ductwork modifications, thermal wheels cost between $700 and $1,000 per thousand CFM (cubic feet per minute) of ventilation. (See the cost/benefit study for an analysis of a typical installation.)

- *MEASURE 8: Improve heating system efficiency by proper control of multiple boilers.*

Guidelines for Implementation:

Many buildings have two or more boilers in their heating systems. Systems with two boilers are generally designed so that each boiler is sized to carry 66% of the building's peak heating demand. These peak demands occur only on a few days each year, while during 90% of the heating season the actual demand for heat in a building is less than 60% of the peak. In other words, either one of the two boilers could carry the entire heating load of the building during 90% of the heating season.

A two-boiler heating system will operate most efficiently if only one boiler is used to supply the heating, except on the few days when both boilers are needed. The second boiler should be held on stand-by and secured by closing valves and dampers.

Potential Savings:

This measure was the subject of a cost/benefit study during the ECP Demonstration. In this study the changeover from a combined two-boiler system to a single boiler with stand-by showed an annual savings of 5% of the heating cost (see Study 7).

Implementation Cost:

The cost of this measure consists of control modifications and possibly some replumbing. In the ECP Demonstration, this measure had a rapid payback period of less than 2 years.

Measures that Reduce Heat Loss from Ventilation and Infiltration

If a building could be sealed air-tight except for the quantity of air needed to allow for the combustion of its heating fuel, heat would be lost from the building primarily by transmission through the exterior surfaces and directly up the stack due to combustion inefficiency. The buildings in Figure II-1 and II-2 would have reductions in the demand for oil of 75% and 33% respectively if they were sealed in such a manner.

It is neither possible nor desirable, however, to have air-tight buildings. Some fresh outdoor air is needed to limit odors and to remove the excess moisture that accumulates in the indoor air.

Whenever there is wind, however slight, the air tends to "pile-up" on the windward side of the building, creating a slight positive pressure on that side. On the leeward side, the flow of air causes a negative pressure.

These opposing pressures create a slight suction which draws the warm indoor air out and pulls cold outdoor air in to replace it through each tiny crack around windows and doors. At higher wind speeds, the suction increases and a larger volume of cold air is drawn into the building.

Infiltration is a particular problem in fire stations and DPW garages. The overhead doors that are common in these buildings are especially leaky and allow a high rate of infiltration. When these doors are opened to allow the passage of apparatus and equipment, a tremendous volume of cold air is introduced into the building. In fact, the rate of heat loss through the open garage doors may exceed the maximum output of the heating system. If these doors remain open for more than a few moments, the building will begin to waste 100% of its heating.

While the infiltration process provides more than adequate ventilation for many buildings, in other buildings, notably schools, additional ventilation is provided by a mechanical system. Duplicating natural processes, these systems consume electrical energy to create a much greater suction for drawing in cold outside air at fixed rates.

It is worth remembering that, even though these ventilation rates are fixed, the amounts of energy consumed to heat the outdoor air supplied at these rates is not. Recalling the new school in Figure II-1 and II-3, at 40 degrees outside, 2.18 gallons of oil per hour are required to heat the outdoor air introduced by the ventilating system. At 0 degrees outside, even though the ventilation rate is unchanged, 5.08 gallons of oil per hour are needed to keep up with the colder air being supplied.

- *MEASURE 9: Shut down ventilation systems during unoccupied periods.*

  Guidelines for Implementation:

  Whenever a building with mechanical ventilation is unoccupied—overnight or on weekends—the ventilation system

should be completely shut down. Often the ventilation system is controlled by the time clock that regulates night set-back. Ideally the ventilation system should have separate or over-ride controls so that, for example, the temperature can be maintained during custodial hours without ventilating the empty building.

Potential Savings:

If the ventilation system of a typical modern school is allowed to run uninterrupted 24 hours a day, seven days a week, the annual energy bill will be 30% higher than if the system were shut down during those unoccupied periods.

Implementation Cost:

In most buildings, this measure will have no associated implementation costs. In others, minor revisions in the control system may have some cost.

- *MEASURE 10: Reduce Ventilation Rates During Occupied Periods.*

Guidelines for Implementation:

Many schools built since 1945 have mechanical ventilation systems that are set to provide fresh air at a rate substantially higher than the 10 cfm/student now required. Unit ventilators—a commonly used system for schools—are relatively easy to inspect and adjust, requiring approximately one man-hour per unit.

If night set-back is to be used, ventilators should be completely closed to outdoor air during the pre-heating of the building, then opened to the normal setting.

Potential Savings:

Analyses of three schools in the ECP Demonstration by the consulting engineering staff show that the annual savings from reducing ventilation rates to 10 cfm/student are between 3.7 and 5.2% of the total fuel consumption (see Studies 8, 9, and 10).

Implementation Cost:

Costs are limited to labor required to adjust each unit vent. The consulting engineering staff estimated costs at $20 per unit vent or from $400 to $800 for an entire school. It is noted in the analyses that the total cost of adjusting the unit vents in each school is recovered in energy savings within 2 years.

- *MEASURE 11: Keep overhead doors closed in fire stations and DPW garages.*

Guidelines for Implementation:

In fire stations, overhead doors should be closed immedi-

ately after the apparatus leaves the station. If no one remains in the station during a response to an alarm, then automatic or radio-controlled door closers should be installed and used.

In maintenance facilities, overhead doors must be opened and closed quite often to move equipment in and out. When these doors are not closed promptly or at all, the heating system pumps most of its output directly to the outdoors. In the spring and fall when outdoor temperatures are above 45 degrees, the doors may remain open all day, necessitating the continuous operation of the heating system. With the doors open, heat is simply pumped out of the building.

To prevent this waste of energy, switches may be installed to shut down the heating system whenever the garage doors are open. If the doors are only opened briefly, the switches will have little if any noticeable effect. If the doors are left open, the switches will prevent the needless operation of the heating system.

Potential Savings:

Studies by R. G. Vanderweil Engineers, Inc. found that automatic door-closers in a typical fire station could save 25% of the annual heating cost, while garage door switches for the heating system of a DPW garage would save 10% (see Studies 11 and 12).

Implementation Cost:

Both studies showed payback periods of less than two years.

Measures that Reduce Heat Transmission

In schools and office buildings, 50 to 70% of the hourly heat loss can be attributed to heat transmission through windows, walls, floors, and roof. The magnitude of transmission losses in an existing building cannot be altered significantly except by installing some type of insulating material in the structure. Although insulation requires a significant capital investment, the resulting energy savings will often pay for the investment after several winters.

The hourly and annual transmission losses from two typical school buildings are shown in Table II-1, expressed in gallons of heating oil. In the table, the transmission losses from a modern school are compared with those of a pre-1945 facility and each are broken down to the major components of the building's structure.

If the roof and walls of these two schools were adequately insulated for the climate in Massachusetts and storm windows were added to all windows, the hourly and annual heat losses due to transmission would be drastically reduced, as shown in Table II-2.

Insulation and storm windows would reduce heat transmission by 50%

TABLE II-1

TRANSMISSION HEAT LOSSES
FROM TWO TYPICAL (UNINSULATED) SCHOOL BUILDINGS*
(IN GALLONS OF HEATING OIL)

Building Component	Hourly Heat Loss ($\Delta t = 70°$)		Annual Heat Loss	
	New School	Old School	New School	Old School
Roof	3.7 gallons	0.6 gallons	7,600 gals.	1,000 gals.
Walls	2.3 gallons	2.0 gallons	4,700 gals.	3,700 gals.
Windows	2.3 gallons	0.9 gallons	3,900 gals.	1,700 gals.
Floor	0.8 gallons	0.1 gallons	4,500 gals.	700 gals.
Total:	8.7 gallons	3.6 gallons	20,700 gals.	7,100 gals.

*Based upon buildings shown in Figures II-1 - II-4

TABLE II-2

TRANSMISSION HEAT LOSSES
FROM TWO TYPICAL SCHOOL BUILDINGS
INSULATED WITH STORM WINDOWS
(IN GALLONS OF HEATING OIL)

Building Component	Hourly Heat Loss ($\Delta t = 70°$)		Annual Heat Loss	
	New School	Old School	New School	Old School
Roof	1.4 gallons	0.2 gallons	2,700 gals.	430 gals.
Walls	0.5 gallons	0.3 gallons	900 gals.	600 gals.
Windows	1.0 gallons	0.5 gallons	2,100 gals.	940 gals.
Floors	0.8 gallons	0.1 gallons	4,500 gals.	700 gals.
Total:	3.7 gallons	1.1 gallons	10,200 gals.	2,670 gals.

annually in the new school and by 62% in the pre-1945 school. At current oil prices and consumption efficiencies, the annual energy savings would be around $6,000 in the new building and $2,500 in the old.

However, it is not always practical or desirable to insulate a building completely or install storm windows on all windows. The potential energy savings must be weighed in relation to the cost of the installation in a particular building. A number of cost/benefit studies related to insulation and storm window installation were performed by R. G. Vanderweil Engineers, Inc. in the ECP Demonstration.

- *MEASURE 12: Install roof insulation to reduce heat transmission.*

Guidelines for Implementation:

The feasibility of installing roof insulation is determined primarily by the construction of the roof. The cost of insulating a roof varies widely from around 20¢ per square foot in a pitched-roof building with an accessible attic to 90¢ per square foot in a flat-roofed building where insulation must either be sprayed on from below or placed on the surface of the existing roof. In the latter case, a new roof must be installed on the surface of the rigid insulation. If a building is slated for re-roofing from normal wear and tear, it is much more economical to insulate the roof at the same time.

In general, ASHRAE Standard 90-75 recommends an insulated roof U-Value of 0.08, although the optimal amount of insulation required in a particular building should be determined by a cost/benefit study.

Potential Savings:

Studies by the consulting engineering staff in the ECP Demonstration (see Studies 13-18) indicate that insulating roofs to the ASHRAE standard will save between 0.14 and 0.04 gallons of oil per square foot of roof per year, depending upon the insulating value of the existing roof. At current oil prices, savings of 2¢ to 6¢ per square foot per year are possible. In a 40,000 square foot school, this represents between $800 and $2,400 saved annually at current oil prices, and as oil prices rise, so will the annual savings.

Implementation Cost:

Conservative estimates by the consulting engineering staff place the current cost of roof insulation between 20¢ and 90¢ per square foot of roof. Municipalities may find substantial discounts, however, through bulk purchases of labor and material for the insulation of several buildings at one time, or by utilizing municipal labor in the installations.

- *MEASURE 13: Install wall insulation to reduce heat transmission.*

Guidelines for Implementation:

In most cases, the insulation of walls requires substantial remodeling of the building interior. As the exterior walls of buildings are either completely solid or have inaccessible cavities within, insulating materials must be applied on the interior surface of the walls. (Some types of insulation may be applied to the exterior wall surface as well.) This usually involves new studs, insulation, new drywalling (plastering), and repainting. In many structures, wall insulation is a sound, practical investment.

Potential Savings:

In the ECP Demonstration, cost/benefit studies of the installation of wall insulation in two pre-1945 schools were conducted by the consulting engineering staff. They determined that insulation of the existing brick walls to ASHRAE standards (U-Value of 0.08) would save 0.4 gallons of oil per square foot of wall per year, or 16¢ per square foot at current oil prices (see Studies 19 and 20).

The two schools have floor areas of 16,000 square feet and 17,000 square feet, with corresponding wall areas (excluding windows) of 8,400 square feet and 11,900 square feet. At current oil prices, the annual savings due to the wall insulation would be $1,340 and $1,900, respectively.

Implementation Cost:

The total cost of insulating these two buildings was estimated to be $1.12 per square foot of wall, including the costs of installing drywalling, drywall finishing, carpentry, and painting. The breakdown of these costs is presented in the cost/benefit studies. As with the preceding measure, the actual costs may be reduced through bulk purchasing and the use of municipal labor.

- *MEASURE 14: Install storm windows to reduce heat transmission and infiltration.*

Guidelines for Implementation:

The windows of buildings transmit much more energy per square foot than any other component of a building. For example, a square foot of window (single pane) transmits 14 times as much heat per minute as a square foot of insulated wall (U-Value of 0.08). (This is one reason why all-glass buildings consume so much energy.)

In municipal buildings, the installation of storm windows will reduce the rate of heat transmission through windows by almost one-half (46%). An additional benefit of storm

windows is a reduction of infiltration of outside air. Storm windows reduce the normal infiltration through cracks around the sash by as much as one-half.

Potential Savings:

The consulting engineering staff studied storm window installations in a school, a town hall, and a fire station (see Studies 21, 22, and 23). These studies reveal that the storm windows would save 0.74 gallons to 0.86 gallons of oil per square foot of window area per year. This represents an annual savings of 1,360 gallons of oil in the school, 350 gallons in the fire station, and 530 in the town hall.

Implementation Cost:

The cost of storm windows varies between $1.71 and $3.00 per square foot, according to the engineering studies. These differentials reflect the fact that certain windows may be fitted with standardized storm windows, while others require more costly custom fitting.

- *MEASURE 15: Reduce heat transmission from windows by installing window insulation or reducing window area.*

Guidelines for Implementation:

As alternatives to storm windows, heat loss through windows can be reduced either by installing a plastic bubble-type insulation on portions of windows or by covering or replacing windows with better insulated materials. These two alternatives are particularly suitable in buildings where the percentage of windows in the exterior walls is large enough that some of the windows in each room (perhaps the upper half) can be covered or blocked without adversely affecting the use of the interior space. (The plastic bubble is translucent to natural light, while the second alternative is completely opaque.) In the ECP Demonstration, engineering studies were made of installing plastic bubble insulation on the upper half of all windows in a pre-1945 school (Study 24), and of eliminating windows from the apparatus floor of a fire station (Study 25).

Potential Savings:

The plastic bubble insulation reduces heat transmission through windows by a bit more than half and will save about 0.48 gallons of oil per square foot of insulated window per year. Replacing windows completely with insulated wall saves 1.73 gallons of oil per square foot of replaced window. At current oil prices, the bubble insulation saves 19¢ per year per square foot, and the elimination of windows saves 70¢ per square foot.

Implementation Cost:

Conservative cost estimates in the ECP Demonstration show that the bubble-type window insulation costs about 86¢ per square foot. The estimated cost of replacing windows with an insulated wall is about $3.50 per square foot. Again, costs may be lower due to bulk purchase and through the use of municipal labor.

Measures that Reduce the Consumption of Electricity

Measures that reduce the consumption of electricity in buildings produce a substantial payoff due to the relatively high cost of electrical energy.

Except in the case of electrically heated buildings, most of the electricity consumed annually in municipal buildings is used by lighting systems. The annual costs of lighting vary between $0.15 and $0.70 per square foot of building area per year. Figure II-5 details the annual costs of lighting a 22' × 30' classroom using six alternative lighting systems. Each of these systems is common, and all provide more than adequate lighting.

The wattage of the lights in the six systems varies substantially—from 2.0 watts per square foot for System B up to 9.09 watts per square foot for System A.

Such variations in the amount of energy consumed to provide a fixed lighting requirement can only be accounted for by the following explanations:

Inefficient fixtures are used to deliver lighting to the rooms. Incandescent lights (System A) require 55 to 70 watts to deliver 1,000 lumens of light. Fluorescent lights (Systems B - F) consume only 12 - 20 watts to produce the same amount of light.

Over-illumination from an excessive number of lighting fixtures can double the power requirements of a lighting system. System E draws 4.0 watts per square foot and produces more light than is required, while System B needs only 2.0 watts per square foot.

The annual costs shown in Figure II-5 assume that the lighting system operates 9 hours per day and 170 days per year. If rooms are also used in the evenings or during the summer, the annual energy costs of each system would be substantially higher. The high cost of lighting can be reduced significantly by the following strategies:

Reduce burning time. When lights are not needed, shut them off.

Reduce illumination levels. Wasteful lighting systems can be improved by removing some lamps and disconnecting ballasts.

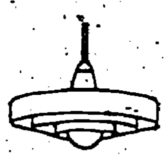
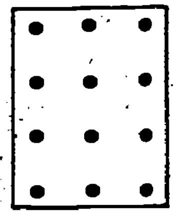
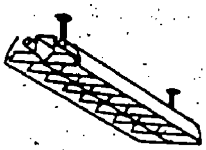
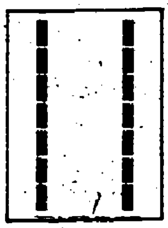
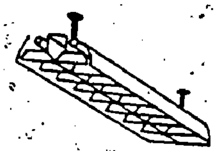
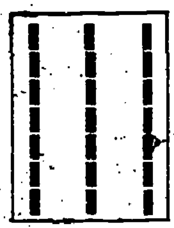
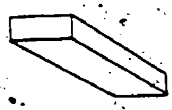
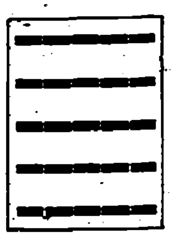
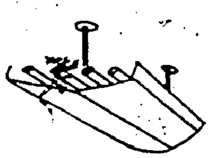
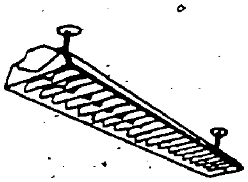
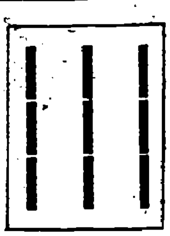
Install a more efficient system to supply lighting to task areas.

- *MEASURE 16: Reduce the burning hours of lighting systems.*

Guidelines for Implementation:

Shutting off lighting systems in all areas whenever

FIGURE II-5

FIXTURE	CEILING PLAN	TOTAL LAMP WATTAGE/ROOM	TOTAL WATTAGE*	ANNUAL ENERGY COST**	ENERGY COST PER SQ. FOOT**
		500 watts/lamp 1 lamp/fixture 12 fixtures/rm. 6000 watts/rm.	6000 watts	$460.00	$0.70
		40 watts/lamp 2 lamps/fixture 14 fixtures/rm. 1120 watts/rm.	1316 watts	$100.00	$0.15
		40 watts/lamp 2 lamps/fixture 21 fixtures/rm. 1680 watts/rm.	1974 watts	$150.00	$0.23
		40 watts/lamp 2 lamps/fixture 25 fixtures/rm. 2000 watts/rm.	2350 watts	$180.00	$0.27
		40 watts/lamp 4 lamps/fixture 14 fixtures/rm. 2240 watts/rm.	2632 watts	$200.00	$0.31
		75 watts/lamp 2 lamps/fixture 9 fixtures/rm. 1350 watts/rm.	1602 watts	$120.00	$0.18

*Includes power consumed by ballasts.
**Based upon annual usage of 1460 hours; cost of electricity @ $0.05 per KWH; room area 660 square feet.

possible saves energy and money. In little-used areas, such as closets, rest rooms, boiler rooms, and basements, lights should remain off when the rooms are not in use. In continuously occupied areas, such as classrooms or offices, daylight should be used to supplement the lighting system. Existing switches should allow lights adjacent to windows to be shut off during the day. If not, modification of switching should be considered.

Potential Savings:

The use of daylight to provide some or all of the lighting in occupied rooms could reduce by a quarter to a third the electricity consumed for lighting. This would save between $50 and $150 per classroom for the systems shown in Figure II-5, and between 4¢ and 23¢ per square foot of building area per year in office buildings.

Implementation Costs:

Usually this measure has no cost except for the effort required to remind people to shut off lighting. In some cases, switching modifications will be required to enable personnel to take full advantage of natural light.

- *MEASURE 17: Reduce illumination levels by using smaller lamps, or by removing lamps and disconnecting ballasts.*

Guidelines for Implementation:

Lighting requirements are based upon the visual tasks to be performed in a specific area of a building. A more visually demanding task such as reading requires a higher level of illumination than would be needed to see adequately in a corridor or stairway. Published standards (IES Handbook, Fifth Edition) for illumination levels are expressed in foot-candles. Normal office work requires 50 - 75 foot-candles, classrooms require 70. General illumination in offices or schools requires 30 foot-candles, and corridors or lobbies require 15.

Many existing buildings have been designed to provide a consistently high level of illumination in all areas. The designer's intention of providing maximum flexibility in the use of rooms, by providing all areas with enough light to meet the most difficult visual tasks, is offset by the high costs of energy required to operate the system.

In many areas, lamps may simply be removed from fixtures to reduce light levels to a reasonable minimum. In fluorescent installations, additional energy can be saved if the ballasts are disconnected as well.

An important point to remember in lamp removal is that the level of room lighting is not proportional to the number of lamps in the room. For example, if *half* of the lamps are removed from each fixture in System E in Figure II-5,

the average level of illumination decreases by only 21%. In many cases, modest reductions in illumination through delamping will produce higher relative energy savings.

Potential Savings:

The energy saved by delamping is proportional to the number and wattage of lamps removed. Based upon annual burning time of 1,530 hours for schools and 2,160 hours for offices, the annual savings per lamp removed are shown in Table II-3.

Implementation Costs:

Delamping can usually be accomplished by local personnel, and costs are limited to their labor. An electrician may be required to disconnect ballasts, at some additional cost.

- *MEASURE 18: Install a more efficient system to supply lighting to task areas.*

Guidelines for Implementation:

The overall efficiency of a building's lighting system (i.e., useful light energy delivered to a task area versus electrical energy consumed by the lighting system) is governed by three factors:

The amount of illumination produced by a lamp per unit of electricity consumed;

The percentage of the total lamp output that is utilized to provide useful illumination for a visual task (coefficient of utilization); and

The placement of lamps in relation to the task areas.

While these factors are interrelated, it is useful to consider measures that logically correspond to each factor.

a. *Lamp efficiency:* Some types of lamps produce much more light per watt of electricity than others, as shown in Table II-4.

In some buildings, it may make sense to replace the existing lighting system with more efficient lamps and fixtures. In schools and offices, the impact of converting to fluorescent fixtures from incandescent is demonstrated in Figure II-5. The annual cost per classroom is $460 for System A (incandescent) and only $100 for System B (fluorescent).

In auditoriums and gymnasiums, it may pay to convert to mercury vapor or metal-halide lamps.

A cost/benefit study of converting the incandescent lighting of a school to a fluorescent system was made in the ECP Demonstration by R. G. Vanderweil (see Study

TABLE II-3

Lamp Removed	Annual KWH saved* School	Annual KWH saved* Office	Annual Savings** School	Annual Savings** Office
1—500 watt incandescent lamp	765 kwh	1080 kwh	$ 38.25	$ 54
1—40 watt fluorescent lamp	61 kwh	86 kwh	$ 3.00	$ 4.30
2—40 watt fluorescent lamps	122 kwh	173 kwh	$ 6.12	$ 8.64
2—40 watt fluorescent lamps and ballasts	144 kwh	203 kwh	$ 7.19	$ 10.15
2—96" fluorescent lamps and ballasts	272 kwh	385 kwh	$ 13.62	$ 19.22

*Annual burning hours: 1,530 hours in schools, 2,160 hours in offices

**Savings based upon cost of electricity of 5¢/kwh

TABLE II-4

Type of Lamp	Efficacy* (Lumens/Watt)
Incandescent	14 - 18
Tungsten Halogen	16 - 20
Fluorescent	50 - 85
Mercury Vapor	40 - 70
Metal-Halide	60 - 80
High-Pressure Sodium	90 - 100

*Includes ballast losses

26).

b. *Coefficient of utilization:* The design and arrangement of the lighting fixtures in a room and the colors and reflectivity of the walls, floor, and ceiling determine how much of the light produced by the lamps actually reaches the task area. A coefficient of utilization (CU) of .50 means that only half of the light supplied by the lamps is useful in performing a visual task—the remainder is absorbed by the fixture, the walls, and the ceiling before it can be used. For fixtures mounted on or recessed into the surface of the ceiling, only 45% to 65% of the light output actually reaches the task area (based upon RCR of 2.7, high reflectivity of ceilings and walls). For suspended fixtures, the utilization is about the same as long as the ceiling remains highly reflective. If the ceiling is only 50% reflective, only 35% to 45% of the lamp output reaches the task level.

These effects should be taken into account when a lighting system is converted.

c. *Lamp placement:* As the distance between the lamp and the task is reduced by half, the required lamp output is reduced by four times. In other words, a 20-watt lamp two feet away from a task provides as much light as an 80-watt lamp four feet away. The placement of lamps in relation to task areas is difficult to anticipate when a building is designed. As a result, many offices and schools are lit so that a uniformly high level of light falls on all areas. While reductions can be made in the general lighting level in existing systems by delamping, additional savings can be achieved by reducing the general light levels and providing supplemental light sources closer to the task surfaces.

In three cost/benefit studies for the ECP Demonstration, R. G. Vanderweil examined the feasibility of substituting small table lamps for existing overhead lighting (see Studies 27, 28, and 29).

Potential Savings:

a. A study by R. G. Vanderweil Engineers, Inc. of replacing incandescent lighting with fluorescent in a school building (Study 26) estimated that electrical consumption would be reduced by 0.71 kwh per square foot per year.

b. Studies of task lighting by the consulting engineering staff in two school libraries and a town hall estimate that between 44% and 64% of the existing lighting energy could be saved by reducing overhead lighting by half and using small table lamps.

Implementation Cost:

The costs of improving the efficiency of existing lighting systems are quite high, and should be investigated only after implementing Measures 15 - 17, which have much higher returns.

Review and Summary of Energy Conservation Measures Recommended for Municipal Buildings

To assist the municipalities in conducting their own audit programs, the following brief discussion organizes the measures described in the preceding section according to the type of municipal buildings in which they are most likely to apply.

While the descriptions of measures in the text are organized according to the principles of energy conservation, the following presentation is broken down by no-cost versus capital-investment measures.

No-Cost Measures Classified by Building Type

From the sixty audit reports submitted by the consulting engineering staff in the demonstration cities and towns, the no-cost measures recommended most often in municipal buildings are indicated in Figure II-6.

Capital Investment Measures Classified by Building Type

Also noted in the sixty audit reports are a number of capital investment measures worthy of further analysis due to their potentially high payback in energy savings. Thirty cost/benefit analyses were conducted to evaluate some of these investments. These analyses are included in this appendix.

The measures suggested in the audit reports are summarized in Figure II-7 by type of municipal building. Figure II-7 should not be construed as recommending specific measures for particular building types, however. Such recommendations must follow a thorough evaluation of the particular costs and savings associated with implementing a measure in a specific building.

Figure II-7 should be interpreted only as a guide to help select potential measures for further study.

EVALUATING INVESTMENT DECISIONS ON BUILDING IMPROVEMENTS

Investing in Improved Building Hardware

Energy saving investments in building improvements should be approached on the basis that they will provide a return above and beyond their implementation cost.

FIGURE II-6

RECOMMENDED NO-COST MEASURES	Pre-1945 Schools	Post-1945 Schools	Town Offices	Fire/Police Stations	Libraries	DPW Garages
	MUNICIPAL BUILDING TYPES					
1) Set back thermostats to 55° during unoccupied periods.	●	●	●		●	
2) Shutdown ventilation system during unoccupied periods.		●			●	
3) Shutdown cooling system during unoccupied periods.			●		●	
4) Reduce unnecessary lighting by delamping.	●	●	●	●	●	
5) Reduce domestic hot water temperature to 110°.	●	●	●	●		●
6) Reduce ventilation rates during occupied periods.	●	●				
7) Measure and adjust burner/boiler efficiency.	●	●	●	●	●	●
8) Calibrate thermostats and other controls.		●		●		
9) Eliminate reheat in HVAC system (where applicable).		●	●		●	
10) Disconnect ballasts when delamping.		●	●			
11) Reduce winter indoor temperature to 68°.	●	●	●	●	●	●
12) Increase summer indoor temperature to 78°.			●	●	●	●
13) Turn off unused lights.	●	●	●	●	●	
14) Use outdoor air for summer cooling.			●	●		●
15) Use blinds/curtains to reduce solar heat gain in summer.			●	●		
16) Use natural lighting when available.	●	●	●		●	

FIGURE II-7

CAPITAL INVESTMENT MEASURES	MUNICIPAL BUILDING TYPES: Pre-1945 Schools	Post-1945 Schools	Town Offices	Fire/Police Stations	Libraries	DPW Garages
Install separate room thermostats	●		●	●		
Heat recovery from boiler stacks	●	●				
Heat recovery (thermal wheels)		●				
Multiple boiler controls	●	●	●			●
Reduce over-ventilation		●				
Automatic door closers				●		●
Roof insulation	●	●	●	●	●	●
Wall insulation	●		●	●	●	
Storm windows	●		●	●	●	
Window insulation/replacement	●		●	●		●
More efficient lighting system	●		●		●	
Install task Lighting		●	●		●	

This discussion assumes that the local decision maker does not have a technical background in financial analysis. It also assumes that improvements under consideration are analyzed by engineers who can provide the manager with the following information on a given improvement:

1. The initial dollar cost of the improvement;
2. The expected annual energy savings in dollars that will result from implementation; and
3. The expected useful life of the improvement.

Given these facts, a manager will want to know the point in time when the capital invested in this improvement can be recovered (i.e., the number of years to payback), what risks ought to be considered in this investment decision, and how risks can be minimized.

To make this determination, a manager must first establish his opportunity or interest cost for investing money. This recognizes the notion that a dollar in hand now is worth more than a dollar expected one year from now. A dollar in hand can be invested in a savings account at, say, six percent interest, so that in one year it would be worth $1.06. This future amount is the real equivalent of a current dollar. In order to compare the worth of an expected future stream of annual savings to the current dollar cost of an investment, this future stream is "discounted" at a rate of interest equivalent to what an alternative investment of these current dollars would realize. Since these current dollars can presumably be invested in a savings account at some interest, this interest rate may be taken as the opportunity cost of investing these dollars in building improvements.

The first step in sound decision-making in investments in building improvements is establishing a "discount rate."

A second important step is recognizing that fuel prices will increase in the future, with the result that the expected stream of annual savings will grow in the future. Assuming constant energy prices and setting a discount rate, a manager would reject an investment where the payback period exceeded the useful life of the improvement. Using the same discount rate but assuming that fuel prices will increase in the future will yield a shorter payback period.

The relationships discussed here are made explicit in Table II-5. The table plots payback periods at a seven percent discount rate for various rates of fuel price escalation, with the ratio of initial investment cost to annual savings specified in the left-hand column.

To illustrate the use of this table, assume that an improvement costing $1,000 will save $100 in energy costs annually, and has a useful life of 15 years. The initial cost to annual savings ratio is 10. At constant fuel prices (i.e., 0% fuel escalation), the payback on this investment is 17.8 years, but if fuel prices increase at the rate of 10% annually, this inflated stream of savings will yield a payback of 8.7 years.

TABLE II-5

YEARS TO PAYBACK AT 7 PERCENT DISCOUNT RATE

Ratio of Initial Cost to Annual Savings	Fuel Price Escalation Rate 0 %	2 %	4 %	6 %	8 %	10 %
1	1.07	1.05	1.03	1.01	0.99	0.97
2	2.23	2.16	2.09	2.03	1.97	1.92
3	3.48	3.32	3.18	3.06	2.95	2.84
4	4.86	4.56	4.31	4.10	3.91	3.74
5	6.37	5.88	5.48	5.15	4.87	4.62
6	8.05	7.28	6.68	6.21	5.81	5.48
7	9.95	8.78	7.93	7.28	6.75	6.32
8	12.13	10.40	9.23	8.36	7.68	7.14
9	14.70	12.16	10.57	9.45	8.60	7.94
10	17.79	14.08	11.97	10.55	9.52	8.72
11	21.72	16.19	13.42	11.67	10.43	9.49
12	27.09	18.54	14.94	12.80	11.33	10.24
13	35.59	21.19	16.53	13.93	12.22	10.97
14	57.82	24.22	18.19	15.09	13.10	11.70
15	*never*	27.77	19.93	16.25	13.98	12.40
16	*never*	32.05	21.77	17.43	14.85	13.10
17	*never*	37.44	23.70	18.62	15.71	13.78
18	*never*	44.72	25.75	19.82	16.57	14.44
19	*never*	55.98	27.93	21.04	17.42	15.10
20	*never*	82.16	30.25	22.27	18.26	15.74

Since under the assumption of zero escalation in fuel cost the 17.8 year payback exceeds the 15 year estimated useful life of the improvement, a decision to reject the investment would be correct. But since fuel prices are certain to increase, this would be the wrong decision. If they increase at 10%, the 8.7 year payback indicates that not only will the cost be fully recovered, but the investment will provide a positive cash flow for another 6.3 years. It is important to assume that energy prices will rise at some rate in the future when analyzing investments in building improvements.

The third step in evaluating investments is establishing the acceptable payback period for a given investment. This period should be somewhat shorter than the useful life of the investment under consideration. In general, the shorter the payback period, the lower the risk that the initial investment cost will not be recovered, either because fuel prices did not rise as rapidly as expected or because the improvement did not last as long as expected. By establishing a payback period shorter than a useful life, the manager also ensures that the investment will yield a return beyond recovery of the initial cost of the investment.

Once the manager has established his payback period criterion, by deciding, for example, that the capital cost of an investment with a useful life of 15 years should be recovered within a 9-year period, the payback tables can be used to determine if the actual payback on a given investment satisfies this criterion. In the case used above, the 9-year payback criterion would be satisfied by the investment, with an actual payback of 8.7 years, assuming a 10% escalation in the price of fuel. The tables on the following pages can be used in this manner to make financially sound investments in building improvements.

To use this method of analysis, the manager must have an engineer establish initial cost, annual savings, and expected life. The manager must establish his discount rate payback period and estimate the rate of fuel price increase. No one can make an accurate point forecast of what this rate will be. A guess in the range of 4% to 8% is quite reasonable, given past rates of fuel price inflation.

TABLE II-6

YEARS TO PAYBACK AT 6 PERCENT DISCOUNT RATE

Ratio of Initial Cost to First Year Savings	Fuel Price Escalation Rate 0%	2%	4%	6%	8%	10%
1	1.06	1.04	1.02	1.00	0.98	0.96
2	2.19	2.12	2.06	2.00	1.95	1.90
3	3.14	3.25	3.12	3.00	2.89	2.80
4	4.71	4.44	4.20	4.00	3.82	3.67
5	6.12	5.67	5.31	5.00	4.74	4.51
6	7.66	6.97	6.44	6.00	5.64	5.33
7	9.35	8.34	7.59	7.00	6.52	6.12
8	11.22	9.79	8.77	8.00	7.39	6.89
9	13.33	11.32	9.98	9.00	8.25	7.64
10	15.73	12.94	11.21	10.00	9.09	8.37
11	18.51	14.68	12.48	11.00	9.92	9.08
12	21.85	16.53	13.77	12.00	10.74	9.78
13	25.99	18.53	16.10	13.00	11.54	10.45
14	31.45	20.70	16.47	14.00	12.33	11.11
15	39.52	23.07	17.87	15.00	13.11	11.75
16	55.24	25.67	19.30	16.00	13.88	12.38
17	never	28.56	20.78	17.00	14.64	12.99
18	never	31.81	22.31	18.00	15.39	13.59
19	never	35.53	23.87	19.00	16.13	14.18
20	never	39.88	25.49	20.00	16.86	14.75

TABLE II-7

YEARS TO PAYBACK AT 8 PERCENT DISCOUNT RATE

Ratio of Initial Cost to First Year Savings	Fuel Price Escalation Rate 0%	2%	4%	6%	8%	10%
1	1.08	1.06	1.04	1.02	1.00	0.98
2	2.27	2.19	2.12	2.06	2.00	1.95
3	3.57	3.40	3.25	3.12	3.00	2.89
4	5.01	4.69	4.43	4.20	4.00	3.83
5	6.64	6.09	5.66	5.30	5.00	4.74
6	8.50	7.62	6.95	6.43	6.00	5.64
7	10.67	9.28	8.31	7.58	7.00	6.53
8	13.27	11.13	9.74	8.75	8.00	7.40
9	16.54	13.19	11.26	9.96	9.00	8.26
10	20.91	15.52	12.86	11.19	10.00	9.10
11	27.55	18.22	14.57	12.44	11.00	9.94
12	41.82	21.41	16.40	13.73	12.00	10.76
13	never	25.31	18.37	15.06	13.00	11.56
14	never	30.35	20.49	16.41	14.00	12.36
15	never	37.44	22.79	17.80	15.00	13.14
16	never	49.57	25.32	19.23	16.00	13.92
17	never	never	28.11	20.69	17.00	14.68
18	never	never	31.23	22.20	18.00	15.43
19	never	never	34.77	23.75	19.00	16.17
20	never	never	38.85	25.35	20.00	16.90

83

TABLE II-8

YEARS TO PAYBACK AT 9 PERCENT DISCOUNT RATE

Ratio of Initial Cost to First Year Savings	Fuel Price Escalation Rate 0%	2%	4%	6%	8%	10%
1	1.09	1.07	1.05	1.03	1.01	0.99
2	2.30	2.22	2.15	2.09	2.03	1.97
3	3.65	3.47	3.32	3.18	3.06	2.95
4	5.18	4.83	4.55	4.30	4.09	3.91
5	6.94	6.33	5.86	5.47	5.14	4.87
6	9.01	7.99	7.25	6.[illegible]	[illegible].20	5.82
7	11.54	9.86	8.74	7[illegible]	[illegible]27	6.76
8	14.77	12.00	10.34	9[illegible]	[illegible].35	7.69
9	19.27	14.48	12.07	10.[illegible]	[illegible].44	8.61
10	26.72	17.46	13.96	11.92	10.54	9.53
11	53.44	21.18	16.03	13.36	11.66	10.44
12	never	26.13	18.32	14.87	12.78	11.34
13	never	33.55	20.89	16.44	13.92	12.23
14	never	48.79	23.81	18.08	15.06	13.12
15	never	never	27.20	19.80	16.22	14.00
16	never	never	31.23	21.61	17.40	14.87
17	never	never	36.20	23.51	18.58	15.74
18	never	never	42.71	25.52	19.78	16.59
19	never	never	52.12	27.65	20.99	17.45
20	never	never	69.38	29.92	22.22	18.29

TABLE II-9

YEARS TO PAYBACK AT 10 PERCENT DISCOUNT RATE

Ratio of Initial Cost to First Year Savings	Fuel Price Escalation Rate 0%	2%	4%	6%	8%	10%
1	1.11	1.08	1.06	1.04	1.02	1.00
2	2.34	2.26	2.19	2.12	2.06	2.00
3	3.74	3.55	3.39	3.24	3.12	3.00
4	5.36	4.99	4.68	4.42	4.19	4.00
5	7.27	6.59	6.07	5.64	5.30	5.00
6	9.61	8.42	7.58	6.93	6.42	6.00
7	12.63	10.55	9.22	8.28	7.57	7.00
8	16.89	13.08	11.64	9.70	8.74	8.00
9	24.16	16.21	13.06	11.20	9.94	9.00
10	never	20.31	15.34	12.79	11.16	10.00
11	[illegible]	26.30	17.95	14.48	12.41	11.00
12	[illegible]	37.52	21.01	16.28	13.70	12.00
13	never	never	24.72	18.21	15.01	13.00
14	never	never	29.39	20.29	16.36	14.00
15	never	never	35.75	22.54	17.74	15.00
16	never	never	45.73	24.99	19.15	16.00
17	never	never	70.45	27.69	20.60	17.00
18	never	never	never	30.70	22.10	18.00
19	never	never	never	34.08	23.63	19.00
20	never	never	never	37.94	25.21	20.00

TABLE II-10

YEARS TO PAYBACK AT 11% DISCOUNT RATE

Ratio of Initial Cost to First Year Savings	Fuel Price Escalation Rate 0%	2%	4%	6%	8%	10%
1	1.12	1.09	1.07	1.05	1.03	1.01
2	2.38	2.30	2.22	2.15	2.09	2.03
3	3.84	3.64	3.46	3.31	3.18	3.06
4	5.56	5.15	4.82	4.54	4.30	4.09
5	7.65	6.88	6.30	5.84	5.46	5.14
6	10.34	8.91	7.94	7.22	6.65	6.20
7	14.08	11.37	9.78	8.69	7.89	7.27
8	20.32	14.47	11.87	10.28	9.17	8.34
9	44.13	18.69	14.29	11.99	10.50	9.43
10	never	25.31	17.16	13.84	11.88	10.53
11	never	41.70	20.70	15.87	13.31	11.64
12	never	never	25.31	18.11	14.80	12.76
13	never	never	31.92	20.61	16.35	13.90
14	never	never	43.79	23.43	17.97	15.04
15	never	never	never	26.67	19.67	16.20
16	never	never	never	30.49	21.45	17.37
17	never	never	never	35.12	23.32	18.55
18	never	never	never	41.02	25.30	19.75
19	never	never	never	49.15	27.38	20.95
20	never	never	never	62.30	29.60	22.17

TABLE II-11

YEARS TO PAYBACK AT 12 PERCENT DISCOUNT

Ratio of Initial Cost to First Year Savings	Fuel Price Escalation Rate 0%	2%	4%	6%	8%	10%
1	1.13	1.10	1.08	1.06	1.04	1.02
2	2.42	2.33	2.25	2.18	2.12	2.06
3	3.94	3.72	3.54	3.38	3.24	3.11
4	5.77	5.32	4.96	4.66	4.41	4.19
5	8.09	7.20	6.55	6.04	5.63	5.29
6	11.23	9.49	8.35	7.54	6.91	6.41
7	16.17	12.39	10.43	9.16	8.25	7.56
8	28.40	16.40	12.89	10.95	9.66	8.72
9	never	22.88	15.90	12.93	11.15	9.92
10	never	42.04	19.79	15.16	12.72	11.14
11	never	never	25.26	17.70	14.39	12.38
12	never	never	34.61	20.65	16.16	13.66
13	never	never	never	24.18	18.06	14.97
14	never	never	never	28.56	20.10	16.30
15	never	never	never	34.34	22.30	17.67
16	never	never	never	42.88	24.69	19.08
17	never	never	never	59.52	27.31	20.52
18	never	never	never	never	30.21	22.00
19	never	never	never	never	33.45	23.52
20	never	never	never	never	37.12	25.08

TABLE II-12

YEARS TO PAYBACK AT 14 PERCENT DISCOUNT RATE

Ratio of Initial Cost to First Year Savings	Fuel Price Escalation Rate 0%	2%	4%	6%	8%	10%
1	1.15	1.13	1.10	1.08	1.06	1.04
2	2.51	2.41	2.33	2.25	2.18	2.11
3	4.16	3.91	3.71	3.53	3.37	3.23
4	6.27	5.72	5.29	4.94	4.65	4.40
5	9.19	7.89	7.14	6.51	6.02	5.62
6	13.99	11.00	9.37	8.29	7.50	6.89
7	29.86	15.60	12.18	10.33	9.11	8.22
8	never	25.47	15.97	12.72	10.87	9.62
9	never	never	21.84	15.63	12.82	11.10
10	never	never	35.49	19.31	15.00	12.65
11	never	never	never	24.37	17.47	14.30
12	never	never	never	32.45	20.32	16.05
13	never	never	never	54.57	23.69	17.92
14	never	never	never	never	27.82	19.92
15	never	never	never	never	33.14	22.07
16	never	never	never	never	40.64	24.41
17	never	never	never	never	53.46	26.96
18	never	never	never	never	never	29.76
19	never	never	never	never	never	32.87
20	never	never	never	never	never	36.38

TABLE II-13

YEARS TO PAYBACK AT 16 PERCENT DISCOUNT RATE

Ratio of Initial Cost to First Year Savings	Fuel Price Escalation Rate 0%	2%	4%	6%	8%	10%
1	1.17	1.15	1.12	1.10	1.08	1.06
2	2.60	2.50	2.40	2.32	2.24	2.17
3	4.41	4.13	3.89	3.69	3.52	3.36
4	6.88	6.19	5.67	5.26	4.92	4.63
5	10.84	9.01	7.88	7.08	6.47	6.00
6	21.69	13.49	10.79	9.26	8.23	7.46
7	never	25.18	15.10	11.98	10.23	9.06
8	never	never	23.49	15.59	12.57	10.80
9	never	never	never	20.97	15.37	12.71
10	never	never	never	31.85	20.97	14.85
11	never	never	never	never	31.85	17.25
12	never	never	never	never	never	20.01
13	never	never	never	never	never	23.25
14	never	never	never	never	never	27.16
15	never	never	never	never	never	32.10
16	never	never	never	never	never	38.81
17	never	never	never	never	never	49.35
18	never	never	never	never	never	75.45
19	never	never	never	never	never	never
20	never	never	never	never	never	never

TABLE II-14

YEARS TO PAYBACK AT 18 PERCENT DISCOUNT RATE

Ratio of Initial Cost to First Year Savings	Fuel Price Escalation Rate 0%	2%	4%	6%	8%	10%
1	1.20	1.17	1.14	1.12	1.10	1.08
2	2.70	2.58	2.48	2.39	2.31	2.24
3	4.69	4.36	4.10	3.87	3.67	3.51
4	7.69	6.78	6.12	5.62	5.22	4.90
5	13.91	10.53	8.85	7.78	7.02	6.44
6	never	19.44	13.05	10.60	9.16	8.17
7	never	never	22.59	14.66	11.80	10.13
8	never	never	never	22.01	15.24	12.42
9	never	never	never	never	20.23	15.14
10	never	never	never	never	29.39	18.51
11	never	never	never	never	never	22.93
12	never	never	never	never	never	29.36
13	never	never	never	never	never	41.43
14	never	never	never	never	never	never
15	never	never	never	never	never	never
16	never	never	never	never	never	never
17	never	never	ever	never	never	never
18	never	never	never	never	never	never
19	never	never	never	never	never	never
20	never	never	never	never	never	never

TABLE II-15

YEARS TO PAYBACK AT 20 PERCENT DISCOUNT RATE

Ratio of Initial Cost to First Year Savings	Fuel Price Escalation Rate 0%	2%	4%	6%	8%	10%
1	1.22	1.19	1.17	1.14	1.12	1.10
2	2.80	2.68	2.57	2.47	2.39	2.31
3	5.03	4.64	4.33	4.07	3.85	3.66
4	8.83	7.53	6.68	6.06	5.58	5.19
5	never	13.17	10.25	8.71	7.70	6.97
6	never	never	17.92	12.68	10.43	9.06
7	never	never	never	20.83	14.28	11.63
8	never	never	never	never	20.85	14.93
9	never	never	never	never	never	19.59
10	never	never	never	never	never	27.56
11	never	never	never	never	never	never
12	never	never	never	never	never	never
13	never	never	never	never	never	never
14	never	never	never	never	never	never
15	never	never	never	never	never	never
16	never	never	never	never	never	never
17	never	never	never	never	never	never
18	never	never	never	never	never	never
19	never	never	never	never	never	never
20	never	never	never	never	never	never

INDEX FOR COST-BENEFIT STUDIES

STUDY 1

Cost Benefit Study of Installing Separate Room Thermostats at the Fowler School
Fall River, MA

I. Building Data

A. Date of Construction - 1897
B. Gross Floor Area - 16,364 sq ft.
C. Fuel Burned in Base Year - 18,000 gal #5 oil.
D. Cost of Fuel Burned - $6,006
E. Cost of Fuel per Gallon - $0.33/gal

II. Summary

The savings derived by installing separate thermostatically controlled valves on the steam pipes, in the classroom of the Fowler School were calculated, and found to be about $270 per year. These valves, four in number, would cost about $400 total.

III. Calculations

A. Assumptions

1. Since the thermostats are on the first floor, and heat rises, the second floor would be five degrees warmer than the first floor if all windows were kept closed.
2. Window area on second floor is 288 sq ft.
3. Roof area is 9,000 sq ft.
4. Wall area on second floor is 2,000 sq ft.
5. Heat content of oil is 140,000 Btu/gal and heating efficiency equals 70 percent (ref 3)

B. Savings to be Realized by the Installation of Thermostatically Controlled Valves in the Four Classrooms on the Second Floor

Because there are no controls on the steam heating system on the second floor, and because heat rises, for calculation purposes it is assumed that the second floor is five degrees warmer than the first floor. This extra five degrees of heat is eventually dumped to the outside air and is, essentially, a heat loss that would not exist if temperature controls kept the upstairs temperature at the same setting as down stairs.

This five degrees of added heat loss is transmitted through the roof, the windows and the walls.

Therefore added loss through:

1. Roof ("U" value = 0.21 Btu/hr-sq ft-deg F (ref 1)).

   (0.21 Btu/hr-sq ft-Deg F) (9,000 sq ft) (5 deg F)

   equals 9,450 Btu/hr.

2. Windows ("U" value = 1.13 Btu/hr-sq ft-deg F (ref 1)).

   (1.13 Btu/hr-sq ft-deg F) (288 sq ft) (5 deg F)

   equals 1,627 Btu/hr

3. Walls ("U" value = .48 Btu/hr-sq ft-Deg F (ref 1)).

   (.48 Btu/hr-sq ft-deg F) (2,000 sq ft) (5 deg F)

   equals 4,800 Btu/hr

The total added heat loss equals:

4,800	Btu/hr
9,450	Btu/hr
1,627	Btu/hr
15,877	Btu/hr

The dollar cost through the heating season.

$$15{,}877\ \frac{\text{Btu}}{\text{hr}}\ \left(24\ \frac{\text{hr}}{\text{day}}\right)\left(30\ \frac{\text{day}}{\text{mo}}\right)\left(7\ \frac{\text{mo}}{\text{yr}}\right)\left(\frac{\text{gal}}{140{,}000\ \text{Btu} \times 0.7}\right)\left(\frac{\$0.33}{\text{GAL}}\right)$$

equals $269/year

C. Cost of Thermostatically Controlled Valves

In this situation, four valves are needed. From manufacturer's data, the installed cost is approximately $100 per valve. Therefore, the total cost is $400.

D. Estimated Useful Lifetime

The estimated useful lifetime of these valves is twenty years (ref 2).

STUDY 2

Cost Benefit Study of Thermostatically Controlled Valves at the Peter Fitzpatrick School (Old Wing), Pepperell, MA

I. Building Data

A. Date of Construction - old wing - about 1920, new wing - about 1960
B. Gross Floor Area - 32,000 sq ft
C. Fuel Burned in Base Year - 27,150 gal #4 oil, 8,820 gal #2 oil
D. Cost of Fuel in Base Year - $9,180 #4 oil, $3,220 #2 oil
E. Cost per Gallon in Base Year - $0.33/gal #4 oil, $0.36/gal #2 oil

II. Summary

The initial cost and annual savings resulting from installing separate room thermostats and control valves on the unit ventilators were calculated. The units are now manually controlled by a damper. This applies only in the old wing of the School. The installed cost of the valves is estimated to be $1,000, and the yearly savings is about $460.

III. Calculations

A. Assumptions

1. Average daytime winter outdoor temperature is 40 deg F.

2. Inside temperature is 75 deg F without control valves and thermostats.

3. Inside temperature could be reduced to 70 deg F with automatic control valves and thermostats.

B. The basic formulas for the loss of heat by transmission and infiltration through a building surface is:

$$q = (cfm \times 1.08 + UA) \times (T_i - T_o) \qquad \text{(ref 1)}$$

where: q = heat loss, Btu/hr
U = coefficient of transmission, Btu/hr-sq ft-deg F
A = area of surface, sq ft
T_i = indoor temperature, deg F
T_o = outdoor temperature, deg F
cfm = cu ft per minute of infiltration

Since the values of U, A, T_o and cfm will remain constant, the energy savings is proportional to the reduction in the indoor temperature T_i. Therefore the yearly savings is:

$$\frac{\$3,200}{yr} - \frac{(70 - 40)\ deg\ F}{(75 - 40)\ deg\ F} \times \frac{\$3,200}{yr} = \$457/yr$$

C. Cost of Thermostatically Controlled Valves

From the manufacturer's data the installed cost for a self-contained control valve is $100 per valve. Therefore the cost of the ten required valves is $1,000.

D. Estimated Useful Lifetime

The useful lifetime is estimated to be twenty years (ref 2).

STUDY 3

Cost Benefit Study of Installing a Natural Gas Domestic Hot Water Heater at the Globe Fire Station, Fall River, MA

I. Building Data

A. Date of Construction - 1951
B. Gross Floor Area - 9,578 sq ft
C. Fuel Burned in Base Year - 18,416 gal #2 oil
D. Cost of Fuel During Base Year - $6,048
E. Cost of Fuel per Gallon - $0.33 per gal

II. Summary

The initial cost and savings resulting from the installation of a separate domestic hot water system for the Globe Fire Station was calculated. The estimated savings per year is $96. The installed cost of a 30 gallon, natural gas hot water heater is estimated to be $240. (The cost of an oil fired hot water heater was estimated to be $580 installed. Due to the high initial cost, this option was given no further consideration.)

III. Calculations

A. Assumptions

1. Natural gas costs $0.003 per cu ft, at last rate block.
2. There are nine sinks and three showers.
3. Oil costs May through September are totally delegated to hot water heating. This amounts of 1,914 gallons at a cost of $632.
4. Heat content of natural gas is 1,000 Btu/cu ft, with heating efficiency of 75 percent (ref 4).
5. Heat content of #2 oil is 140,000 Btu/gal (ref. 4).
6. Overall heating efficiency of existing hot water system is fifty percent.
7. There is a 100 deg. F. temperature rise in the hot water heater.

B. Cost of a New Domestic Hot Water Tank

During the base year, the fire station used 1,914 gallons on oil, during the summer season, to heat domestic hot water. Assuming a 100 deg F temperature rise in the existing hot water heater, and an overall heating efficiency of fifty percent, the following amount of hot water was used during the summer season.

$$1{,}914\ \frac{\text{gal}}{\text{season}} \times 140{,}000\ \frac{\text{Btu}}{\text{gal}} \times 0.5\ \text{eff.} = \dot{m} \times 1.0\ \frac{\text{Btu}}{\text{lb deg F}} \times 100\ \text{deg F (ref 2)}.$$

where m equals pounds of water per season.

Therefore $\dot{m}$ equals 1,339,800 lb/season.

The average use per hour is:

$$1{,}339{,}800\ \frac{\text{lb}}{\text{season}} \times \frac{\text{cu ft}}{62.4\ \text{lb}} \times \frac{7.48\ \text{gal}}{\text{cu ft}} \times \frac{\text{season}}{5\ \text{mo}} \times \frac{\text{mo}}{30\ \text{day}} \times \frac{\text{day}}{24\ \text{hr}}\ \text{or 4 gal/hr.}$$

From reference one, the maximum use is approximately six times the average, or 24 gal/hr.

This maximum use can be accommodated by a 30 gallon gas, hot water heater. This unit would cost about $240 including installation and piping.

$$1{,}914\ \text{gallons of oil} \times 140{,}000\ \frac{\text{Btu}}{\text{gal}} \times 0.5\ \text{eff.}$$

$$\text{equals}\ \chi\ \text{cu ft} \times 1{,}000\ \frac{\text{Btu}}{\text{cu ft of natural gas}} \times 0.75\ \text{eff}$$

Where χ equals total amount of natural gas.

Therefore χ equals 176,640 cu ft of natural gas at 0.003 per cu ft. This comes to a yearly cost of $536 vs $632 for existing system.

C. Savings Due to Installation of a National Gas Hot Water System

The savings result from the difference in fuel costs heating the hot water with the boiler, as opposed to heating it using a separate system. In this case, the estimated savings per year are:

$632 - $536 = $96/year.

D. EstimatedUseful Lifetime

The estimated useful lifetime of the water heater is twenty years (ref. 3).

Cost Benefit Study of Stack Heat Recovery
at the Fowler School
Fall River, MA

I. Building Data

A. Date of Construction - 1897
B. Gross Floor Area - 16,364 sq ft.
C. Fuel used in Base Year - 18,000 gals #5 oil
D. Cost of Oil in Base Year - \$6,006
E. Cost of Oil per Gallon in Base Year - \$0.33/gal

II. Summary

The initial cost and annual savings resulting from installing a flue gas economizer system were estimated. The system can recover heat which is lost up the stack in the flue gas. A total savings estimate of about \$735 per year was calculated. The installed cost of the system was estimated to be about \$5,000.

III. Calculations

A. Assumptions

1. 550 deg F flue gas temperature.
2. 8 percent CO_2 in the flue gas.
3. Flue gas temperature can be held to a steady 300 deg F after the heat exchanger.
4. 150,000 Btu/gal heat content of #5 oil. Boiler efficiency is 70 percent.

B. Heat Recovery Savings

The equation governing the annual amount of heat that can be recovered is:

$$q = MxCx(t_1 - t_2) \quad \text{(ref 1)}$$

Where:

q = Btu/yr
M = lbs of flue gas per year
C = Specific heat of flue gas 0.25 Btu/lb-deg F
t_1 = Temperature of the flue gas entering the heat exchanger (i.e. 600 deg F)
t_2 = Temperature of the flue gas leaving the heat exchanger (i.e. 300 deg F)

The equation governing the amount of flue gas produced (F) per 1,000 Btu fuel input is:

$$F = .72\ (.12 + \frac{15.8}{\%CO_2}) \quad \text{(ref 2)}$$

Therefore:

$$F = .72\ (.12 + \frac{15.8}{8}) = \frac{1.5 \text{ lbs}}{1{,}000 \text{ Btu fuel input}}$$

The amount of Btu's used in a year is:

$$18{,}000\ \frac{\text{gal}}{\text{yr}} \times 150{,}000\ \frac{\text{Btu}}{\text{gal}} = 2.7 \times 10^9\ \frac{\text{Btu}}{\text{yr}}$$

Therefore:

$$M = \frac{1.5 \text{ lbs}}{1{,}000 \text{ Btu fuel input}} \times 2.7 \times 10^9\ \frac{\text{Btu}}{\text{yr}} = 4.05 \times 10^6\ \frac{\text{lbs}}{\text{yr}}$$

And:

$$q = 4.05 \times 10^6\ \frac{\text{lbs}}{\text{yr}} \times \frac{0.25 \text{ Btu}}{\text{lb x deg F}} \times (550-300) = 25.31 \times 10^7\ \frac{\text{Btu}}{\text{yr}}$$

The savings in dollars is equal to:

$$\frac{25.31 \times 10^7 \text{Btu}}{\text{yr}} \times \frac{\text{gal}}{150{,}000 \text{ Btu} \times 0.7} \times \frac{\$0.33}{\text{gal}} = \frac{\$785}{\text{yr}}$$

The cost to run the system is estimated at \$50/yr. Therefore, the net savings is:

$$\$785 - \$50 = \$735$$

D. Cost Estimate

The cost of the system is estimated to be about \$5,000 from manufacturer's data.

E. Estimated Useful Lifetime

The estimated useful lifetime of the system is ten years.

STUDY 5

Cost Benefit Study of Stack Heat Recovery
at the Peter Buckely Administration Building
Concord, MA

I. Building Data

A. Date of Construction - About 1960.
B. Gross Floor Area - 32,193 sq ft.
C. Fuel used in Base Year - 22,450 gal #2 oil.
D. Cost of Oil in Base Year - $7,196.
E. Cost of Oil per Gallon in Base Year - $0.32/gal.

II. Summary

The initial cost and annual savings resulting from installing a flue gas economizer system were estimated. The system can recover heat which is lost up the stack in the flue gas. A total savings estimate of about $1000 per year was calculated. The installed cost of the system was estimated to be about $3,500.

III. Calculations

A. Assumptions

1. 600 deg F flue gas temperature.
2. 8 percent CO_2 in the flue gas.
3. Flue gas temperature can be held to a steady 300 deg F after the economizer.
4. 140,000 Btu/gal. heat content of oil. Boiler efficiency is 70 percent

B. Heat Recovery Savings

The equation governing the annual amount of heat that can be recovered is:

$$q = M x C x (t_1 - t_2) \quad \text{(ref 1)}$$

Where:

q = Btu/yr.
M = Lbs of flue gas per year.
C = Specific heat of flue gas 0.25 Btu/lb-deg F
t_1 = Temperature of the flue gas entering the heat exchanger (i.e. 600 deg F)
t_2 = Temperature of the flue gas leaving the heat exchanger (i.e. 300 deg F)

The equation governing the amount of flue gas produced (F) per 1,000 Btu fuel input is:

$$F = 0.72\ (0.12 + \frac{14.4}{\%CO_2}) \quad \text{(ref 2)}$$

Therefore:

$$F = 0.72\ (0.12 + \frac{14.4}{8}) = 1.38 \frac{\text{lbs}}{1{,}000 \text{ Btu fuel input}}$$

The amount of Btu's used in a year is:

$$22{,}460 \frac{\text{gal}}{\text{yr}} \times \frac{140{,}000 \text{ Btu}}{\text{gal}} = 3.144 \times 10^9 \frac{\text{Btu}}{\text{yr}}$$

Therefore:

$$M = \frac{1.38 \text{ lbs}}{1{,}000 \text{ Btu}} \times \frac{3.144}{\text{year}} \times 10^9 \text{Btu} = 4.338 \times 10^6 \frac{\text{lbs}}{\text{yr}}$$

And:

$$q = 4.338 \times 10^6 \frac{\text{lbs}}{\text{yr}} \times \frac{0.25 \text{ Btu}}{\text{lbs} \times \text{deg F}} \times (600\text{-}300)\text{deg F} =$$

$$3.25 \times 10^8 \frac{\text{Btu}}{\text{yr}}$$

The savings in dollars is equal to:

$$\frac{3.25 \times 10^8 \text{Btu}}{\text{yr}} \times \frac{\text{gal}}{140{,}000 \text{ Btu} \times 0.7} \times \frac{\$0.32}{\text{gal}} = \frac{\$1060}{\text{yr}}$$

The cost to run the system is estimated at $50/yr. Therefore, the net savings is:

$$\$1060 - \$50 = \$1010.$$

D. Cost Estimate

The cost of the system is estimated to be about $3,500 from manufacturer's data.

E. Estimated Useful Lifetime

The estimated useful lifetime of the system is ten years.

STUDY 6

Cost Benefit Study of an Air to Air
Heat Recovery System from the Pool Area
at the Attleboro High School, Attleboro, MA

I. Building Data

A. Date of Construction - 1962
B. Gross Floor Area - 430,000 sq ft
C. Fuel Burned in Base Year - 279,514 gal #5 oil.
D. Cost of Fuel During Base Year - $87,598
E. Cost of Fuel per Gallon - $0.31/gal.

II. Summary

The amount of heat recoverable by an air to air heat exchanger (heat wheel) was calculated and found to save about $2,600 per year in energy costs. The installed cost of such a system is estimated to be $20,000.

III. Calculations

A. Assumptions

1. 10,000 cfm of air is exhausted from the pool area at a temperature of 80 degrees.

2. Seasonal heat wheel efficiency for the applicable temperatures is 60 percent.

3. Pool is ventilated 24 hours per day.

4. Heat content of oil equals 140,000 But/gal. Heating efficiency 70 percent (ref 2).

5. There are 5293 deg-days per year during the heating season from October 1 through May 1 (Ref 3).

B. Energy Savings Possible by Using an Air to Air Heat Recovery System

The equation governing the recoverable energy is:

$$q = \frac{1.08 \text{ Btu}}{\text{hr x cfm x deg F.}} \times \text{cfm} \times \frac{\text{deg-day}}{\text{yr}} \times \frac{24 \text{ hrs}}{\text{day}} \times$$

efficiency

where q = total heat used - Btu/yr.

The savings amount to:

$$(823,167 \times 10^6 \frac{\text{Btu}}{\text{yr}}) (\frac{\text{gal}}{140,000 \text{ Btu} \times 0.7}) (\$0.31/\text{gal}) \text{ or}$$

$2,600 per year.

C. Cost Estimate

1. Cost of 10,000 cfm installed air to air heat wheel on the pool roof with additional ductwork and wiring from manufacturer's data $2.0/cfm.

2. 10,000 cfm x $2.0/cfm = $20,000.

D. Estimated Useful Lifetime

The estimated useful lifetime is fifteen years.

STUDY 7

Cost Benefit Study of Lead/Lag
Boiler Controls at the
Concord Town House, Concord, MA

I. Building Data

A. Date of Construction - 1860
B. Gross Floor Area - 19,564 sq. ft.
C. Fuel Burned in Base Year - 7,152 Gallons #2 oil
D. Cost of Fuel in Base Year - $2,293
E. Cost per Gallon in Base Year - $0.32/Gallon

II. Summary

The initial cost and annual savings resulting from the installation of lead/lag controls on the steam heating boilers were estimated, over a typical heating season (Oct. 1 - May 1). A savings of approximately $115 per year was calculated at a cost of about $150. At present there are two boilers that operate simultaneously. The lead/lag controls will run only one boiler, with the other starting up only when additional heat load is called for. By going to a system such as this, the overall boiler efficiency is increased. The only controls needed, is one additional thermostat set outside the building, set an estimated temperature of 25 deg F.

III. Calculations

A. Assumptions

1. The peak heating loss is about 30 Btu/hr sq ft at 0 deg F outside temperatures.

2. There are two boilers, each having 66 percent of the total peak capacity required.

3. The total enclosed square footage is 19,564 sq ft.

4. Inside temperature is set at 70 deg F during the heating season.

5. The above assumptions defines an overall U value for the building of 0.43 Btu/hr-sq ft-deg F.

6. There is no inherent or practical reason why both boilers can't be rewired so that they can run on separate controls.

7. The engineering weather data (ref 1) is applicable

B. Energy Savings by Reducing Short Cycling of Boilers

By using Reference 1, one can develop a curve of total heat required vs. number of heating days for a typical Boston heating season. From the curve, one can see that only one boiler of the assumed size is needed 85 percent of the time. The additional boiler is needed only on the very cold days in winter. If one goes to a lead/lag control, the first boiler will be "on" for a much greater percentage of the time. This will increase its efficiency (Ref 2). In our judgement this will produce at least an over-all efficiency increase of 5 percent.

Therefore:

$$\frac{\$2,293}{yr} \times 0.05 = \frac{\$115}{yr}$$

C. Cost Estimated

1. One (1) outdoor air temperature thermostat, wiring, and modifications to existing controls, $150 from manufacturer's data.

D. Estimated Useful Lifetime

The estimated useful lifetime of new thermostat and wiring is twenty years.

STUDY 8

Cost Benefit Study of the Reduction
of Ventilation Air at the Willard School
Concord, MA

I. Building Data

A. Date of Construction - 1958
B. Gross Floor Area - 39,500 sq ft
C. Fuel Burned in Base Year - 45,191 gal #2 oil
D. Cost of Fuel in Base Year - $14,493
E. Cost Per Gallon in Base Year - $0.32/gallon

II. Summary

The initial cost and annual savings resulting from the reduction of ventilation air brought in by the unit ventilators were estimated. This rebalancing is needed because most of the unit ventilators were found to be over supplying ventilation air. The annual savings was estimated to be about $480, and the cost of readjusting the unit ventilators is estimated at $400.

III. Calculations

A. Assumptions

1. Existing ventilation rate - 15 cfm/occupant.
2. New ventilation rate - 10 cfm/occupant. (Mass. code)
3. Population density - 25 students/unit ventilator.
4. Boiler efficiency - 70 percent (ref. 1).
5. 20 unit ventilators.
6. Estimated average daytime winter outdoor temperature - 40 deg F.
7. School is open 180 days - 10 hr a day.
8. Inside temperature - 70 deg F.
9. Heat content of #2 oil equals 140,000 Btu/gal.

B. Savings by Reduction in Ventilation Rate

The equation governing the energy required to heat outdoor air up to indoor temperature is:

$$q = 1.10 \times cfm \times \Delta T \qquad \text{(Ref. 2)}$$

where q = Btu/hr
1.10 = constant btu/hr x cfm x deg F.
cfm = cu ft/min
ΔT = temperature difference (inside-outside) deg F.

Therefore the energy savings for the year is equal to:

$$\frac{1.10 \text{ Btu}}{\text{hr-cfm-deg F.}} \times \frac{(15\text{-}10) \text{ cfm}}{\text{occupant}} \times (70\text{-}40) \text{ deg F} \times \frac{25 \text{ occupants}}{\text{unit vent.}}$$

$$\times\ 20 \text{ unit vent} \times \frac{10 \text{ hr}}{\text{day}} \times \frac{180 \text{ day}}{\text{year}} = 148.4 \times 10^6 \text{ Btu/year}$$

The dollar savings is equal to

$$\frac{148.4 \times 10^6 \text{ Btu}}{\text{year}} \times \frac{\text{gal}}{140{,}000 \text{ Btu} \times 0.7} \times \frac{\$0.32}{\text{gal}} = \$483\text{/year}$$

C. Cost Estimate

1. $20/man-hr for field labor, from control manufacturer.
2. 1 hour required per unit vent.
3. $20/hr x 20 unit vents x 1 hr/unit vent = $400.

D. Estimated Useful Lifetime

Since this change is just a readjustment of existing equipment, the "estimated useful lifetime" is equal to the remaining life of the equipment.

STUDY 9

Cost Benefit Study of the Reduction of Ventilation Air at the Acton/Boxborough Junior High School

I. Building Data

A. Date of Construction - About 1960
B. Gross Floor Area - 66,600 sq ft.
C. Fuel Burned in Base Year - 7,760 Gals #2 Oil, 72,5[illegible]0 Gals #4 Oil
D. Cost of Fuel in Base Year - $2,930 #2 Oil, $22,980 [illegible] Oil
E. Cost Per Gallon in Base Year - $0.37/Gal #2 Oil, $0.31/Gal #4 Oil.

II. Summary

The initial cost and annual savings resulting from the reduction of ventilation air brought in by the unit ventilators were estimated. This rebalancing is needed because most of the unit ventilators were found to be over supplying ventilation air. The annual savings was estimated to be about $780 and the cost of adjusting the unit ventilators is estimated at $800.

III. Calculations

A. Assumptions

1. Existing ventilation rate - 15 cfm/occupant.
2. New ventilation rate - 10 cfm/occupant. (Mass. code)
3. Population Density - 25 students/unit ventilator.
4. Boiler efficiency - 70 percent (ref. 1).
5. 40 unit ventilators.
6. Estimated average daytime winter outdoor temperature - 40 deg F.
7. School is open 180 days - 10 hours a day.
8. Outdoor temperature, 70 deg F.
9. Heat content of #4 oil - 145,000 Btu/gal.

B. Savings by Reduction in Ventilation Rate

The equation governing the energy required to heat outdoor up to indoor temperature is:

$$q = 1.10 \times cfm \times \Delta T \quad \text{(ref. 2)}$$

where: q = Btu/hr
1.10 = Constant Btu/Hr x cfm c deg F.
cfm = cu ft/min
ΔT = temperature difference (inside-outside) deg. F.

Therefore the energy savings for the year is equal to:

$$\frac{1.10 \text{ Btu}}{\text{hr-cfm-degF}} \times \frac{(15-10)\text{ cfm}}{\text{occupant}} \times (70-40)\text{ deg F} \times \frac{25 \text{ occupant}}{\text{unit vent.}}$$

$$\times 40 \text{ Unit Vents} \times \frac{10 \text{ hr}}{\text{day}} \times \frac{180 \text{ day}}{\text{year}} = 297 \times 10^6 \text{ Btu/year}$$

The dollar savings is equal to:

$$\frac{247 \times 10^6 \text{ Btu}}{\text{year}} \times \frac{\text{gal}}{145{,}000 \text{ Btu} \times 0.7} \times \frac{\$0.31}{\text{gal}} = \$781/\text{year}$$

C. Cost Estimate

1. $20/man-hr for field labor from control manufacturer.
2. 1 hour required per unit vent.
3. $20/hour x 40 unit vents x one hour/unit vent = $800.

D. Estimated Useful Lifetime

Since this change is just a readjustment of existing equipment, the estimated useful lifetime is equal to the remaining life of the equipment.

STUDY 10

Cost Benefit Study of the Reduction of Ventilation Air at the Peter Fitzpatrick School, Pepperell, MA

I. Building Data

A. Date of Construction - Old Wing - About 1920
New Wing - About 1960

B. Gross Floor Area - 32,000 sq ft

C. Fuel Burned in Base Year - 27,150 gal #4 oil
8,820 gal #2 oil

D. Cost of Fuel in Base Year - $9,180 #4 oil
$3,220 #2 oil

E. Cost per Gallon in Base Year - $0.33/gal #4 oil
$0.36/gal #2 oil

II. Summary

The initial cost and annual savings resulting from the reduction of ventilation air brought in by the unit ventilators were estimated. This rebalancing is needed because most of the unit ventilators were found to be over supplying ventilation air. The annual savings was estimated to be about $625, and the cost of readjusting the unit ventilators is estimated at $500.

III. Calculations

A. Assumptions

1. Existing ventilation rate - 15 cfm/occupant.
2. New ventilation rate - 10 cfm/occupant. (Mass. code)
3. Population density - 25 students/unit ventilator.
4. Boiler efficiency - 70 percent (ref 1).
5. 25 unit ventilators.
6. Estimated average daytime winter outdoor temperature - 40 deg F.
7. School is open 180 days - 10 hrs a day.
8. Inside temperature - 70 deg F.
9. Heat content of #2 oil equals 140,000 Btu/gal.

B. Savings by Reduction in Ventilation Rate

The equation governing the energy required to heat outdoor air up to indoor temperature is:

$$q = 1.10 \times cfm \times \Delta T \quad \text{(ref 2)}$$

where q = Btu/hr
1.10 = constant Btu/hr x cfm x deg F.
cfm = cu ft/min
ΔT = temperature difference (inside-outside) deg F.

Therefore the energy savings for the year is equal to:

$$\frac{1.10\ \text{Btu}}{\text{hr-cfm-deg F.}} \times \frac{(15\text{-}10)\ \text{cfm}}{\text{occupant}} \times (70\text{-}40)\ \text{deg} \times \frac{25\ \text{occupants}}{\text{unit vent.}} \times$$

$$25\ \text{units} \times \frac{10\ \text{hr}}{\text{day}} \times \frac{180\ \text{day}}{\text{year}} = 185.5 \times 10^6\ \text{Btu/year}$$

The dollar savings is equal to

$$\frac{185.5 \times 10^6\ \text{Btu}}{\text{year}} \times \frac{\text{gal}}{140{,}000\ \text{Btu} \times 0.7} \times \frac{\$0.33}{\text{gal}} = \$625/\text{year}$$

C. Cost Estimate

1. $20/man-hr for field labor, from control manufacturer.
2. 1 hour required per unit vent.
3. $20/hr x 25 unit vents x 1 hr/unit vent = $500.

D. Estimated Useful Lifetime

Since this change is a readjustment of existing equipment, the useful lifetime is equal to the remaining life of the equipment.

STUDY 11

Cost Benefit Study of an Automatic Door Closure Device on the Fire Station No. 2 in Acton, MA

I. Building Data

A. Date of Construction - Approx. 1950
B. Gross Floor Area - 5400 sq ft
C. Fuel Burned in Base Year - 810,000 cu ft Natural Gas
D. Cost of Fuel in Base Year - $2,430
E. Cost of Fuel Per Cu. Ft. - $0.003/cu ft
F. Average Incremental Cost of Gas (8/76) - $0.003/cu ft

II. Summary

As of the present time there are no automatic door closure devices installed on the main doors of the Acton Fire Station. As a result, when an alarm is sounded, and the firefighters go to answer the call, the doors can be, and are, left open for long periods of time. The following analysis showed that at least $585 per year can be saved in energy costs if these doors were automatically closed. The amount of hot air that can be lost during a cold day during the winter can be considerable. The cost of an automatic door closure system, on the two front doors, is estimated to be $800 from manufacturer's data.

III. Calculations

A. Assumptions

1. Inside garage temperature is kept to 60 deg F.
2. Door is open two hours per day for 200 days of heating season.
3. Infiltration Rates: 2 airchanges per hour with door closed and 4 with door open (apparatus floor only).
4. Average winter temperature equals 35^{o} deg F.
5. Heat content of natural gas equals 1,000 Btu/cost.
6. Seasonal efficiency equals 75 percent (ref 1).

B. Infiltration Savings with the Use of an Automatic Door Closure System.

$$\frac{(4\text{-}2)\text{ Air Changes}}{\text{hr}} \times \frac{423{,}000\text{ ft}^3}{\text{air change}} \times \frac{\text{hr}}{60\text{ min}} \times \frac{1.08\text{ Btu}}{\text{hr x deg F x cfm}}$$

$$\times\ (60^{o}-35^{o}) \times \frac{400\text{ hr}}{\text{yr}} = 155 \times 10^{6}\text{Btu/yr.}$$

This heat loss costs:

$$155 \times 10^{6}\text{Btu/yr} \times \frac{\text{cu ft}}{1000\text{ Btu}} \times 0.75 \times \frac{\$0.003}{\text{cu ft}} = \$583$$

C. Add Cost of Installation

From manufacturer's data, the installed cost is approximately $800.

D. Estimated Useful Lifetime

The estimated useful lifetime of the motor that powers the automatic door closing device is fifteen years.

STUDY 12

Cost Benefit Study of Switches on the Garage Doors to Control the Heating System at the DPW Building, Acton, MA

I. Building Data

A. Date of Construction - About 1965
B. Gross Floor Area - 18,644 sq ft
C. Fuel Used in Base Year - 1,744,000 cu ft of natural gas
D. Cost of Natural Gas in Base Year - $5,118
E. Cost of Gas per cu ft - $0.003/cu ft
F. Incremental Cost of Gas (8/76) - $0.003/cu ft

II. Summary

The initial cost and annual savings resulting from installing switches on the garage doors to shut off the heating system when the doors are open were estimated. The amount of hot air that can be lost during a cold day during the winter if the doors are left open needlessly, can be considerable. A total savings estimate of about $465 per year was calculated. The installed cost of the system was estimated to be about $750.

III. Calculations

A. Assumptions

1. Average winter temperature equals 35 deg F.
2. Door is open two hours per day for 200 days of heating season.
3. Inside garage temperature is kept to 60 deg F.
4. Infiltration rates: two air changes per hour with door closed and four with door open.
5. Heat content of natural gas equals 1,000 Btu/cu ft.
6. Seasonal efficiency equals 75 percent (ref 1).

B. Infiltration Savings with the use of an Automatic Door Closure System.

$$\frac{(4\text{-}2)\text{ air change}}{\text{hr}} \times \frac{325{,}000\text{ cu ft}}{\text{air change}} \times \frac{\text{hr}}{60\text{ min}} \times \frac{1.08\text{ Btu}}{\text{hr x deg F x cfm}}$$

$$\times\ (60\text{-}35)\text{ deg F} \times \frac{400\text{ hr}}{\text{yr}} = 116.98 \times 10^6\text{ Btu/yr}$$

This energy costs:

$$116.98 \times 10^6 \frac{\text{Btu}}{\text{yr}} \times \frac{\text{cu ft}}{1{,}000\text{ Btu} \times 0.75} \times \frac{\$0.003}{\text{cu ft}} = \$466/\text{yr}$$

D. Cost Estimate

The cost of the automatic switches installed on the doors and wired into the control of the heating system is $750 from manufacturer's data.

E. Estimated Useful Lifetime

The estimated useful lifetime is ten years for the door switches.

STUDY 13

Cost Benefit Study of Roof Insulation on the Thoreau School, Concord, MA

I. Building Data

A. Date of Construction - 1951
B. Gross Floor Area - 34,400 sq ft
C. Fuel Burned in Base Year - 38,500 gal #2 oil
D. Cost of fuel in Base Year - $14,000
E. Cost of Fuel per Gallon - $0.36/gallon

II. Summary

Since a reroofing job is contemplated at this time, the initial cost and annual savings resulting from the installation of additional insulation were calculated. Roof insulation reduces energy consumption by reducing the thermal loss (transmission) through the roof. There are many different types of roof insulation and each type has to be evaluated on its own merits. Polyurethane Roof Deck Insulation was selected for this study. A total savings estimate of $2,900 was calculated. The additional cost was estimated to be $22,000.

III. Calculations

A. Assumptions

1. "U" value of existing roof. Built-up roof with a metal deck and fiberboard ceiling and an air space, equals 0.22 Btu/hr-sq ft-deg F (ref 1)

2. "U" Value with additional insulation as recommended in reference 2. 0.08 Btu/hr-sq ft-deg F.

3. Roof Area Equals 39,400 sq ft.

4. Boiler efficiency is 70 percent (ref 3)

5. Heating season from Oct. 1 to May 1 equals 5,942 degree days (ref 4).

6. Effects such as loss of solar heat gain, rain, snow, and occupancy will be neglected.

7. 140,000 Btu/gal #2 oil.

B. Transmission Savings by Additional Roof Insulation

$$= \frac{(0.22 - 0.08)\ \text{Btu}}{\text{hr} \times \text{ft}^2 \times {}^{\circ}\text{F}} \times 39{,}400\ \text{sq ft} \times \frac{5{,}942\ \text{deg-day}}{\text{year}}$$

$$\times \frac{24\ \text{hr}}{\text{day}} \times \frac{\$0.36}{\text{Gal}} \times \frac{\text{gal.}}{140{,}000\ \text{Btu} \times 0.7}$$

$= \$2,888$

C. Cost Estimate

1. $0.65/sq ft for 2 inches of additional installed insulation from manufacturer's data.

2. $\frac{\$0.65}{\text{sq ft}} \times 34{,}400\ \text{sq ft} = \$22{,}360$

D. Estimated Useful Lifetime

The estimated useful lifetime is twenty years.

STUDY 14

Cost Benefit Study of Sprayed on Roof Insulation on the Briggs Corner Fire Station, Attleboro, MA

I. Building Data

A. Date of Construction - 1969
B. Gross Floor Area - 2,100 sq ft
C. Fuel Burned in Base Year - 304,500 cu ft of Natural Gas
D. Cost of Fuel Burned in Base Year - $913
E. Cost of Fuel per Cu. Ft. - $0.003/cu ft
F. Cost of Electricity - $0.055/kWh

II. Summary

The annual savings resulting from installing spray on foam, roof insulation was calculated; and estimated to be $715 per year. The savings result by reducing the thermal transmission through the roof, saving both heating and air conditioning costs. The installed cost of the insulation is estimated to be $1,900.

III. Calculations

A. Assumptions

1. Gross roof area equals 2,100 sq ft
2. Roof is built up on a metal deck, with no insulation, and has a "U" value of 0.67 Btu/hr-sq ft-deg F (ref 1).
3. The building is heated to 65 deg F.
4. During the heating season from Oct. 1 - May 1, there are 5,923 degree-days (ref 5).
5. "U" value with addition of insulation as recommended in reference 2, will be 0.08 Btu/hr-sq ft-deg F.
6. Thirty percent of the building is air conditioned during the summer.
7. Solar effects are neglected.
8. Heat content of natural gas is 1000 Btu/cu ft.
9. Heating system efficiency is 75 percent (ref 7).

B. Transmission Savings By Addition of Roof Insulation, During the Heating Season

$$\frac{(0.67-0.08)\ \text{Btu}}{\text{hr-sq ft-deg F}} \times 2100\ \text{sq ft} \times \frac{5{,}923\ \text{deg day}}{\text{year}} \times \frac{24\ \text{hours}}{\text{day}}$$

$$\times\ \$0.003/\text{cu ft} \times \frac{\text{cu ft}}{1000\ \text{Btu} \times 0.75} = \$704/\text{year}.$$

C. Savings Accrued by Addition of Roof Insulation During the Cooling Season

From reference 3, the following weather data was obtained for the Boston Area:

Temperature Range Deg. F	Mean Temperature Deg. F	Hours of Occurrence During the Year
95-99	97	6
90-94	92	36
85-89	87	107
80-84	82	245
75-79	77	388

Using this data, and knowing that the air conditioned section of this building is to be held at 75 deg, the heat flow across the roof can be calculated. The heat gain across the roof is a linear function of its "U" value. The higher the U value, the higher the heat gain.

The equation governing the heat gain through the roof is:

$q = UA\,\Delta T$ (ref. 4)

where q = Btu/hr
U = Btu/hr-sq ft-deg F.
A = sq ft
ΔT = Temperature difference across the roof deg F

In this case, one is interested in the energy saved due to insulation, therefore, the appropriate "U" value to use to calculate energy savings is the difference between the insulated and uninsulated "U" value. This number is 0.67 - 0.08 = 0.59 Btu/hr-sq ft-deg F.

The appropriate area, A, is 30 percent of 2,100 sq ft or 693 sq ft.

Therefore, for the five mean temperatures listed, the energy saved per cooling season is calculated as follows:

0.59 Btu/hr-sq ft-deg F (693 sq ft) (97-75 deg F) (6 hr) = 54×10^3 Btu
0.59 Btu/hr-sq ft-deg F (693 sq ft) (92-75 deg F) (36 hr) = 250×10^3 Btu
0.59 Btu/hr-sq ft-deg F (693 sq ft) (87-75 deg F) (107 hr) = 525×10^3 Btu
0.59 Btu/hr-sq ft-deg F (693 sq ft) (82-75 deg F) (245 hr) = 701×10^3 Btu
0.59 Btu/hr-sq ft-deg F (693 sq ft) (77-75 deg F) (388 hr) = 317×10^3 Btu

for a total savings of 1.8×10^6 Btu/year.

The dollar savings is:

$$= 1.8 \times 10^6 \text{ Btu/yr} \left(\frac{1.4 \text{ kWh}}{\text{ton-hr}}\right) \left(\frac{\text{ton-hr}}{12{,}000 \text{ Btu}}\right) \left(\frac{\$0.055}{\text{kWh}}\right)$$

$$= \$12/\text{year}$$

Therefore the total heating and cooling savings are \$704 + \$12 = \$716 /year.

D. Cost Estimate

1. \$0.90/sq ft for 2 inch sprayed-on insulation installed from manufacturer's data.

2. \$0.90/sq ft x 2,100 sq ft = \$1,890.

E. Estimated Useful Lifetime

The useful lifetime is estimated to be fifteen years (ref 6, see asbestos).

STUDY 15

Cost Benefit Study of Spray-on Roof Insulation at DPU Building, Acton, MA

I. Building Data

A. Date of Construction - About 1965
B. Gross Floor Area - 18,644 sq ft
C. Fuel Used in Base Year - 1,744,500 cu ft of natural gas plus 17,270 kWh of electricity for air conditioning
D. Cost of Natural Gas in Base Year - \$5,118
E. Cost of Electricity in Base Year - \$8,719
F. Cost of Gas per cu ft - \$0.003/cu ft
G. Cost of Electricity/kWh - \$0.055/kWh
H. Incremental Cost of Gas (8/76) - \$0.003/cu ft
I. Incremental Cost of Electricity (8/76) - \$0.055/kWh

II. Summary

The initial cost and annual savings resulting from the addition of spray-on roof insulation were estimated. Roof insulation will reduce energy use by reducing the thermal loss (transmission) through the roof during the winter, and by reducing the heat flow into the building during the summer. A total savings estimate of about \$650 per year was calculated based on the reduction of heating and air conditioning. The installed cost of the insulation was estimated to be about \$8,500.

III. Calculations

A. Assumptions

1. Existing Transmission - From reference 1 for a built up roof, on a metal deck with one inch insulation, the "U" factor equals 0.15 Btu/hr sq ft deg F.

2. Insulated Transmission - Using one inch of sprayed on cellulose foam, applied to the inside roof area, the "U" factor changes to 0.09 Btu/hr-sq ft-deg F.

3. The installed cost, as quoted by manufacturer, is \$0.45/sq ft.

4. Roof area equals 18,644 sq ft.

5. Thirty percent of the building is air conditioned during the summer, with the indoor temperature maintained at 75 deg F.

6. As air cooled air conditioning system uses 1.4 kilowatt-hours per ton-hour of cooling (ref 4).

7. Heat content of natural gas is 1,000 Btu/cu ft.

8. Heating efficiency equals 75 percent (ref 7).

7. Solar gain during the winter is negligible.

8. There are 5,923 degree days over heating season (Oct. 1 to May 1) with the building open six days per week, 15 hours per day (ref. 5).

B. Transmission Savings through Roof During Heating Season

Heat saved = (0.15 - 0.09) (18,644 sq ft) (5,923 deg-day) (24 hr) = 159×10^6 Btu over heating season.

$$159 \times 10^6 \text{ Btu } \left(\frac{\$0.003}{\text{cu ft}}\right)\left(\frac{\text{cu ft}}{1000 \times .75}\right) = \$636/\text{yr} \text{ (at current gas rates)}$$

C. Transmission Savings through Roof During Cooling Season

From reference 2, the following weather data was obtained for the Boston area.

Temperature Range deg F.	Mean Temperature-deg F	Hours of Occurrence During the Year
95-99	97	6
90-94	92	36
85-89	87	107
80-84	82	245
75-79	77	388

Using this data, and knowing that in the air conditioned section of the building is to be held at 75 deg., the heat flow across the roof can be calculated. The heat gain across the roof in a linear function of its U value. The higher the U value, the higher the heat gain. In this case, the U value without insulation is 0.15 Btu/hr-sq ft-deg F; with insulation the U value is 0.09 Btu/hr-sq ft-deg F. The energy savings is, therefore, a function of the difference of these two numbers.

The equation governing the heat gain through the roof is:

$q = UA\Delta T$ (ref 3)

where q = Btu/hr
U = Btu/hr sq ft-deg F
A = sq ft
ΔT = Temperature differential across the roof.

In this case, one is interested in the energy saved due to insulation; therefore, the appropriate U value to use to calculate energy savings is the difference between the insulated and un-insulated U-values. This number is 0.15 0.09 = 0.06 Btu/hr-sq ft-deg F.

The appropriate area, A, is 30% of 18,644 sq ft or 5,593 sq ft.

Therefore, for the five mean temperatures listed, the energy saved per cooling season, is calculated as follows:

0.06 Btu/hr-sq ft-deg (5593 sq ft) (97-75 deg) (6 hrs)/yr = 44.29×10^3 Btu/year

0.06 Btu/hr-sq ft-deg (5593 sq ft) (92-75 deg) 36 hrs)/yr = 205.37×10^3 Btu/year

0.06 Btu/hr-sq ft-deg (5593 sq ft) (87-75 deg) (107 hrs)/yr = 466.79×10^3 Btu/year

0.06 Btu/hr-sq ft-deg (5593 sq ft) (82-75 deg) (245 hrs)/yr = 575.51×10^3 Btu/year

0.06 Btu/hr-sq ft-deg (5593 sq ft) (77-75 deg) (388 hrs)/yr = 260.41×10^3 Btu/year

for a total savings of $1,552 \times 10^3$ Btu/year.

The dollar savings is:

$$1552 \times 10^3 \text{ Btu/yr} \left(\frac{1.4 \text{ kWh}}{\text{ton-hr}}\right) \left(\frac{\text{ton-hr}}{12,000 \text{ Btu}}\right) \left(\frac{\$0.055}{\text{kWh}}\right)$$

= $10/year (at last block of current electricity rates)

Therefore the total heating and cooling savings are:

$636 + $10 = $646/year

D. Cost Estimate

1. $0.45/sq ft for one inch sprayed-on insulation (installed, from manufacturer's data.

2. $0.45/sq ft x 18,644 sq ft = $8,398.

E. Estimated Useful Lifetime

The estimated useful lifetime is fifteen years (see ref 6 under asbestos).

STUDY 16

Cost Benefit Study of Roof Insulation
at the Flint Street Fire Station
Fall River, MA

I. Building Data

A. Date of Construction - 1873
B. Gross Floor Area - 7,000 sq ft
C. Fuel Burned in Base Year - 11,254 gal #2 oil.
D. Cost of Fuel Burned in Base Year - $3,872
E. Cost of Fuel per Gallon - $0.35/gal

II. Summary

The estimated savings resulting from insulating the unused attic floor of the Flint Street Fire Station was calculated and found to be about $65 per year. The installed cost of such insulation would be about $725.

III. Calculations

A. Assumptions

1. Because of the many slopes on this roof, and since the attic is not used, in this analysis, the attic will be insulated, using a rigid, foam insulation.

2. The insulated area is 3,500 sq ft.

3. There are 5,408 degree-days in the heating season from Oct. 1 to May 1 (ref 1).

4. Heat content of #2 oil is 140,000 Btu/gal.

5. Heating system efficiency is 70 percent (ref 4)

6. Burdened labor rate for installation is $15 per hour.

B. Transmission Savings by the Addition of Insulation on the Attic Floor

From reference 2, the "U" value between the second floor ceiling and the outside air, in the vertical direction, is 0.12 Btu/hr-sq ft-deg F. With the addition of 1 1/2 inches of commercially available rigid foam, installed on the floor of the unused attic, the "U" is decreased to 0.08 Btu/hr-sq ft-deg F, which is the recommended "U" value from reference 3.

The savings is a function of the difference of these "U" values. Therefore, the energy saved is

$$\frac{(0.12 - 0.08)\ \text{Btu}}{\text{hr-sq ft-deg F}}\ (3{,}500\ \text{sq ft})\ (5{,}408\ \frac{\text{deg-days}}{\text{year}})\ (24\ \frac{\text{hr}}{\text{day}})$$

which equals 18.0×10^6 Btu/year

The dollar savings is:

$$(18.0 \times 10^6\ \frac{\text{Btu}}{\text{year}})\ (\frac{\text{gal}}{140{,}000\ \text{Btu} \times 0.7})\ (\frac{\$0.35}{\text{gal}}) = \$64/\text{year}$$

C. Cost of Insulation

The uninstalled cost of the insulation is $173 per 1,000 sq ft or $173/1,000 sq ft (3.5) = $605 total.

Since the insulation is highly portable and is cut easily with a knife, it should not take more than one man-day to install. Assuming a burdened labor rate of $15 per hour, the installation cost should be $15/hr x 8 hr = $120.

Therefore:

Installation Cost	$605
Insulation Cost	120
	$725 total

D. Estimated Useful Lifetime

The estimated useful lifetime of the attic insulation is fifteen years (from manufacturer's data).

STUDY 17

Cost Benefit Analysis of Installing Spray-On Roof Insulation at the Carrol School, Fall River, MA

I. Building Data

A. Date of Construction - app. 1950.
B. Gross Floor Area - 23,914 sq ft.
C. Fuel Burned in Base Year - 19,532 Gal #5 oil
D. Cost of Fuel in Base Year - $6,507
E. Cost of Fuel per Gallon - $0.33/gal.

II. Summary

The savings accrued in a year's time due to the installation of sprayed on cellulose foam room insulation was calculated and estimated to be about $1,360 per year. The installed cost was estimated to be $16,700.

III. Calculations

A. Assumptions

1. Roof area is 23,914 sq ft.
2. Heating Season from Oct. 1 to May 1 contains 5,408 deg-days (ref 1).
3. Heat content of #5 oil is 140,000 Btu/gal.
4. Heating system efficiency is 70 percent (ref 5).
5. Effects such as loss of solar gain, rain, snow, and occupancy will be neglected.

B. Transmission Savings by Addition of Roof Insulation

From reference 2, the existing "U" value for the build-up wood deck roof is 0.21 Btu/hr-sq ft-deg F. With the addition of 1 3/4 inches of sprayed on cellulose foam insulation, the "U" value drops to 0.08 Btu/hr-sq ft-deg F, which is recommended "U" value for this climate zone (ref. 3). The savings realized is a function of the difference of these two values.

The energy savings in a year's time is:

$$(0.21 - 0.08 \frac{\text{Btu}}{\text{hr-sq ft-deg F}}) \text{ (23,914 sq ft) } (5{,}408 \frac{\text{deg-day}}{\text{yr}}) (24 \frac{\text{hr}}{\text{day}})$$

which equals 403×10^6 Btu/yr.

This saves:

$$403 \times 10^6 \text{ Btu/yr } (\frac{\text{gal}}{140{,}000 \text{ Btu} \times 0.7}) (\frac{\$0.33}{\text{gal}}) = \$1{,}356\text{/year}$$

C. Cost of Sprayed on Roof Insulation

From manufacturer's data, the installed cost of 1 3/4 inches of sprayed on cellulose insulation is about $0.70 per sq ft.

Therefore, the total cost is:

$0.70 (23,914) = $16,740

D. Estimated Useful Lifetime

The useful lifetime is estimated to be fifteen years (ref 4, under asbestos insulation).

STUDY 18

Cost Benefit Study of Roof Insulation
on the Lakeview School
Tyngsborough, MA

I. Building Data

A. Date of Construction - 1956
B. Gross Floor Area - 19,800 sq ft
C. Fuel Burned in Base Year - 25,000 gal #2 oil
D. Cost of Fuel in Base Year - $8,400
E. Cost of Fuel per Gallon - $0.33/Gal

II. Summary

Since a reroofing job will be necessary in the future, the initial cost and annual savings resulting from the installation of additional insulation were calculated. Roof insulation reduces energy consumption by reducing the thermal loss (transmission) through the roof. There are many different types of roof insulation and each type has to be evaluated on its own merits. Polyurethane Roof Deck Insulation was selected for this study. A total savings estimate of $1,400 was calculated. The additional cost was estimated to be about $12,900.

III. Calculations

A. Assumptions

1. "U" factor of existing roof, a built-up roof with a metal deck and fiberboard ceiling and an air space, = 0.22 Btu/hr x sq ft deg F (ref 1).
2. "U" Factor with additional insulation as recommended in ref 2).
   0.08 Btu/hr-sq ft-deg F.
3. Roof Area equals 19,800 sq ft.
4. Seasonal boiler efficiency is 70 percent (ref 3).
5. Heating season from Oct. 1 to May 1 equals 6,226 degree days (ref 4).
6. Effects such as loss of solar heat gain, rain, snow and occupancy will be neglected.
7. Heat content of #2 oil is 140,000 Btu/gal.

B. Transmission Savings by Additional Roof Insulation

$$= \frac{(0.22 - 0.08)\ \text{Btu}}{\text{hr-sq ft-deg F}} \times 19{,}800\ \text{sq ft} \times \frac{6{,}226\ \text{deg-day}}{\text{yr}}$$

$$\times \frac{24\ \text{hr}}{\text{day}} \times \frac{\$0.33}{\text{gal}} \times \frac{\text{gal}}{140{,}000\ \text{Btu} \times 0.7}$$

= $1,394/year

C. Cost Estimate

1. $0.65/sq ft for 2 inches of additional polyurethane roof deck insulation installed. Manufacturers' data.

   Therefore:

   $$\frac{\$0.65}{\text{sq ft}} \times 19{,}800\ \text{sq ft} = \$12{,}870$$

D. Estimated Useful Lifetime

The estimated useful lifetime of the new roof is twenty years.

STUDY 19

Cost Benefit Analysis of the Installation of Wall Insulation at the Highland School, ~~Fall River~~, MA

I. Building Data

A. Date of Construction - 1901
B. Gross Floor Area - 16,968 sq ft.
C. Fuel Burned in Base Year - 19,501 gal #5 Oil
D. Cost of Fuel in Base Year - $6,500.
E. Cost of Fuel per Gallon - $0.38/gal

II. Summary

The savings realized by the reduction in transmission losses through the walls, by the installation of insulation, was calculated and found to be about $2,400 per year. The initial cost of the insulation was estimated to be about $13,350.

III. Calculations

A. Assumptions

1. Outside wall area is 11,916 sq ft.
2. The window area is about 1,400 sq ft (78, 3' x 6' windows).
3. During the heating season from Oct. 1 to May 1, there are 5,408 deg-days (ref 1).
4. Boiler efficiency is 70 percent (ref 5)
5. Heat content of #5 oil is 140,000 Btu/gal.
6. "U" value for uninsulated brick wall equals 0.48 Btu/hr-sq ft-deg F (ref 2).
7. The walls are of brick construction and are uninsulated.

B. Savings Due to Wall Insulation

The "U" value for an uninsulated brick wall equals 0.48 Btu/hr-sq ft-deg F. The insulated wall will be designed to meet the ASHRAE standard for this area (ref 3), which is 0.08 Btu/hr-sq ft-deg F. This can be done with 3 1/2 inches of rolled fiberglass insulation.

The energy savings is a function of the difference of the two aforementdoned "U" values and is written as follows:

$$(0.48 - 0.08 \text{ Btu/hr-sq ft-deg F})\ (11{,}916 \text{ sq ft})\ (5{,}408\ \frac{\text{deg-day}}{\text{year}})$$

$$\times\ (24\ \frac{\text{hr}}{\text{day}}) \text{ which equals } 618.9 \times 10^6 \text{ Btu/yr.}$$

In dollars, this is a savings of:

$$(618.9 \times 10^6\ \frac{\text{Btu}}{\text{yr}})\ (\frac{\text{gal}}{140{,}000 \text{ Btu} \times 0.7})\ (\frac{\$0.38}{\text{gal}}) = \$2{,}399/\text{year}$$

C. Cost of Wall Insulation

This cost involves the cost of 3 1/2 inches of fiberglass insulation, plus the cost of erecting a gypsum board wall and finishing costs. These are summarized below (ref 4):

Installed insulation cost -	($0.19/ft^2) =	$2,264
Installed drywall cost -	($0.27/ft^2) =	3,217
Drywall finishing cost -	($0.27/ft^2) =	3,217
Carpentry cost - (20 $235/day)	=	3,336
Painting cost -	($0.11/ft^2) =	1,311
		$13,345

D. Estimated Useful Lifetime

The estimated useful lifetime of the insulated wall is twenty years.

STUDY 20

Cost Benefit Study of Wall Insulation at the Davol School, Fall River, MA

I. Building Data

A. Date of Construction [illegible]82
B. Gross Floor Area - 15,984 sq ft
C. Fuel Burned in Base Year - 2,366,200 cu ft of Natural Gas
D. Cost of Fuel in Base Year - $6,185
E. Average Cost of Fuel per cu ft - $0.003/cu ft
F. Incremental Cost of Fuel (8/76) - $0.003/cu ft

II. Summary

The savings due to the installation of wall insulation at the Davol School was calculated and found to be about $1,750 per year. The initial cost was estimated to be $9,400.

III. Calculations

A. Assumptions

1. Outside wall area equals 8,400 sq ft.
2. Window area equals 1,700 sq ft.
3. During the heating season from Oct. 1 to May 1, there are 5,408 deg-days (ref 1).
4. Natural gas has a heat content of 1,000 Btu per cu ft.
5. Boiler efficiency is 75 percent (ref 4).

B. Savings Due to Wall Insulation

From reference 2, the "U" value for a brick wall, uninsulated equals 0.48 Btu/hr-sq ft-deg F. The insulated wall will be designed to meet the ASHRAE Standard for this area (ref. 3) which is 0.08 Btu/hr-sq ft-deg F.)

The energy savings is a function of the difference of these two "U" values and is written as follows:

$$(0.48 - 0.08 \text{ Btu/hr-sq ft-deg F})\ (8{,}400 \text{ sq ft})\ \left(5{,}408\ \frac{\text{deg day}}{\text{yr}}\right)$$

$$\left(24\ \frac{\text{hr}}{\text{day}}\right) \text{ which equals } 436 \times 10^6 \text{ Btu/yr.}$$

In dollars, this is a savings of (based on the last block of current gas rates)

$$436 \times 10^6\ \frac{\text{Btu}}{\text{yr}} \left(\frac{\text{cu ft}}{1{,}000 \times 0.75 \text{ Btu}}\right) \left(\frac{\$.003}{\text{cu ft}}\right) = \$1{,}743/\text{year}$$

C. Cost of Wall Insulation

This cost involves the cost of 3 1/2 in. of fiberglass insulation, plus the cost of erecting a gymsum board wall and finishing. The costs are estimated to be as follows: (Ref 5)

Installed insulation cost	- ($0.19/ft^2)	=$1,596
Installed drywall cost	- ($0.27/ft^2)	= 2,268
Drywall finishing cost	- ($0.27/ft^2)	= 2,268
Carpentry cost	-(20$235/day)	= 2,352
Painting	- ($0.11/ft^2)	= 924
		$9,408

D. Estimated Useful Lifetime

The estimated useful lifetime of the insulated wall is twenty years.

STUDY 21

Cost Benefit Study of the Installation
of Storm Windows at the Davol School
Fall River, MA

I. Building Design

A. Date of Construction - 1892
B. Gross Floor Area - 15,984 sq ft
C. Fuel Burned in Base Year - 2,366,200 cu ft of Natural Gas.
D. Cost of Fuel in Base Year - $6,185
E. Cost of Fuel per cu ft - $0.003/cu ft

II. Summary

The savings due to the installation of triple track, aluminum storm windows at the Davol School was calculated and found to be about $425 per year. The initial cost was estimated to be $2,900.

III. Calculations

A. Assumptions

1. Window area equals 1,700 sq ft (94, 3 ft by 6 ft windows).
2. During the heating season from Oct. 1 to May 1, there are 5,408 deg-days (ref 1).
3. Natural gas has a heat content of 1,000 Btu per cu ft.
4. Seasonal boiler efficiency is 75 percent (ref 4).
5. There will be a 10 percent breakage per year of the storm windows.

B. Savings Due to the Installation of Storm Windows

Storm windows change the "U" value of the window from 1.13 to 0.54 Btu/hr-sq ft-deg F. (ref 2).

Therefore the savings over the heating season amount to:

$$(1.13-0.54 \text{ Btu/hr-sq ft-deg F})\ (1{,}700 \text{ sq ft})\ (5{,}408\ \frac{\text{deg days}}{\text{yr}})$$

$$(24\ \frac{\text{hr}}{\text{day}}) = 130 \times 10^6 \text{ Btu/yr}.$$

There is also a savings due to the elimination of the ambient air infiltration through the cracks in the windows. This infiltration loss can be calculated as follows:

The crack length along a 3 ft by 6 ft window equals:

6 ft x 2	=	12
3 ft x 3	=	9
		21 ft total

Assuming a 10 mile per hour wind and referring to reference 3, this yields an infiltration of 0.35 cu ft/min per linear foot of crack. This factor can be reduced by one-half with the use of storm windows. Therefore, the total infiltration equals:

$$(\frac{0.35}{2}\ \frac{\text{cu ft}}{\text{min ft}})\ (21 \text{ ft})\ (94 \text{ windows}) = 345\ \frac{\text{cu ft}}{\text{min}}\ (\text{cfm})$$

The equation governing the annual energy savings is:

$$\frac{\text{Btu}}{\text{yr}}\ (q) = \frac{1.08 \text{ Btu}}{\text{hr x cfm x deg F.}} \times \text{cfm} \times \frac{\text{deg-day}}{\text{yr}} \times \frac{24 \text{ hrs}}{\text{day}}$$

Therefore:

$$q = 1.08 \times 345 \times 5{,}408 \times 24 = 48.3 \times 10^6 \text{ Btu/yr}.$$

Therefore the total savings due to storm windows is:

$$(48.3 + 130) \times 10^6\ \frac{\text{Btu}}{\text{yr}}\ (\frac{\text{cu ft}}{1{,}000 \text{ Btu} \times 0.75})\ (\frac{\$0.003}{\text{cu ft}}) = \$713$$

subtracting breakage (see cost section), this yields an annual savings of $713 - $290 = $423 per year (based on current gas rate.

C. Cost of Storm Windows

The cost of 94 3 ft by 6 ft storm windows is approximately $2,900 (about #30 per window).

For breakage, subtract 10 percent of this figure per year from savings.

D: Estimate Useful Lifetime

The estimated useful lifetime of the storm windows is twenty years.

STUDY 22

Cost Benefit Study of Storm Windows
on the Town Hall, Dunstable, MA

I. Building Data

A. Date of Construction - 1908
B. Gross Floor Area - 2,800 sq ft
C. Fuel Burned in Base Year - 770,000 cu ft natural gas
D. Cost of Fuel in Base Year - $1,730
E. Average Cost of Fuel per cu ft - $0.0022/cu ft
F. Incremental Cost of Fuel 18/76 -$0.003 cu.ft.

II. Summary

The initial cost and annual savings resulting from the installation of triple track, aluminum storm windows on the Dunstable Town Hall were calculated. It was estimated that the installation of storm windows will save $310 per year in fuel costs. The installed cost of the storm windows is about $1,850.

III. Calculations

A. Assumptions

1. The U value of a single pane of glass is 1.13 Btu/hr sq ft deg F (ref 1).
2. The U value of single pane glass with a storm window is 0.54 Btu/hr-sq ft-deg F (ref 1).
3. Window area is 615 sq ft.
4. There are 25 windows 3 ft by 5 ft approximately.
5. There are 20 windows 2 ft x 6 ft approximately.
6. There are 6,226 deg-days per year during the heating season from Oct 1 through May 1 (ref 3).
7. Infiltration crack width 1/32 of an inch.
8. Ten mile per hour wind for infiltration calculation.
9. Heat content of natural gas equals 1,000 Btu/cu ft.
10. Furnace efficiency equals 75 percent (ref 4).

B. Transmission Savings by the Addition of Storm Windows

The amount of energy saved is a function of the difference in heat lost through storm windows vs. single pane glass windows.

Therefore:

$$\left(\frac{1.13-0.54\ \text{Btu}}{\text{hr-sq ft-deg}}\right)(615\ \text{sq ft})\left(6{,}226\ \frac{\text{deg day}}{\text{year}}\right)\left(24\ \frac{\text{hr}}{\text{day}}\right)$$

which amounts to a savings of 54.2×10^6 Btu/year.

In dollars, this amounts to

$$\frac{54.2 \times 10^6\ \text{Btu}}{\text{yr}} \times \left(\frac{\text{cu ft}}{1{,}000\ \text{Btu} \times 0.75}\right) \times \frac{\$0.003}{\text{cu ft}}$$

which equals $216/year

C. Infiltration Savings through Addition of Storm Windows

Every double hung window has a crack where it abutts the track and where the top part of the window abutts the bottom part of the window. During the winter cold air infiltrates through these cracks, adding to the heating load. This infiltration can be reduced by one-half with the use of storm windows. One can calculate the infiltration as follows:

$$\frac{19\ \text{ft}}{\text{window}} \times 25 = \quad 475\ \text{ft}\ (3' \times 5'\ \text{windows})$$

$$\frac{18\ \text{ft}}{\text{window}} \times 20 = \quad \underline{360\ \text{ft}}\ (2' \times 6'\ \text{windows})$$

835 ft

Assuming a 10 mile per hour wind, and referring to ref. 2, this yields an infiltration of 0.35 cu ft/min per linear foot of crack for a window without a storm window. Therefore total infiltration with a storm window equals:

$$\frac{0.35}{2}\ \frac{\text{cu ft}}{\text{min ft}} \times 835\ \text{ft} = 146\ \frac{\text{cu ft}}{\text{min}}\ (\text{cfm})$$

The equation governing the annual energy savings is:

$$\frac{Btu}{yr}(q) = \frac{1.08\ Btu}{hr \times cfm \times deg\text{-}F.} \times cfm \times \frac{deg\text{-}day}{yr} \times \frac{24\ hrs}{day}$$

Therefore:

$$q = 1.08 \times 146 \times 6{,}226 \times 24 = 23.5 \times 10^{6}$$

In dollar savings this equals:

$$\frac{23.5 \times 10^{6}\ Btu}{yr}\left(\frac{cu\ ft}{1{,}000 \times 0.75}\right) \times \frac{\$0.003}{cu\ ft} = \$94$$

Therefore the total savings per year by using storm windows equals:

215 + \$94 = \$309

D. Cost Estimated

From manufacturer's data, the cost and installation of a triple track storm window using double strength glass is \$3.00 per square foot

$$\frac{\$3.00}{sq\ ft} \times 615\ sq\ ft = \$1{,}845$$

E. Estimated Useful Lifetime

The estimated useful lifetime of an aluminum triple track storm window is twenty years.

STUDY 23

Cost Benefit Study of Storm Windows
on the North Main Street Fire Station
Fall River, MA

I. Building Data

A. Date of Construction - 1873
B. Gross Floor Area - 6,000 sq ft.
C. Fuel Burned in Base Year - 9,205 Gal #2 oil.
D. Cost of Fuel in Base Year - $2,971
E. Cost of Fuel per Gallon - $0.32/gal.

II. Summary

The initial cost and annual savings resulting from the installation of storm windows on the North Main Street Fire Station were calculated. It was estimated that the installation of storm windows will save $155 per year in fuel costs. The installed cost of the storm windows is about $950.

III. Calculations

A. Assumptions

1. The U value of a single pane of glass is 1.13 Btu/hr sq ft deg F (ref 1).
2. The U value of single panel glass with a storm window is 0.54 Btu/hr-sq ft-deg F (ref 1).
3. Window area is 473 sq ft, including skylight.
4. There are six windows 8 ft by 3.5 ft with an arched top.
5. There are ten windows 7 ft by 3.5 ft.
6. There is one skylight 5 ft by 6 ft.
7. There are 5,408 deg-days per year during the heating season from Oct 1 through May 1 (ref. 3).
8. Storm windows will be installed over rectangular portion or arched windows only and sealed at the seven foot level.
9. Infiltration crack width 1/32 of an inch.
10. 10 mile per hour wind for infiltration calculation.
11. The heat content of #2 oil is 140,000 Btu/gal.
12. The heating efficiency is 70 percent (ref 4).

B. Transmission Savings by the Addition of Storm Windows

The amount of energy saved is a function of the difference in heat lost through storm windows vs. single pane glass windows.

Therefore:

$$\left(\frac{1.13-0.54\ \text{Btu}}{\text{hr-sq ft-deg}}\right)(473\ \text{sq ft})\left(5{,}408\frac{\text{deg day}}{\text{year}}\right)\left(24\ \frac{\text{hr}}{\text{day}}\right)$$

which amounts to a savings of 36.2×10^6 Btu/year.

In dollars, this amounts to

$$36.2 \times 10^6\ \frac{\text{Btu}}{\text{yr}}\left(\frac{\text{gal}}{140{,}000\ \text{Btu} \times 0.7}\right)(\$0.32/\text{gal})\ \text{which}$$

equals $117/year

C. Infiltration Savings through Addition of Storm Windows

Every double hung window has a crack where it abutts the track and where the top part of the window abutts the bottom part of the window. During the winter cold air infiltrates through these cracks, adding to the heating load. This infiltration can be reduced by one-half with the use of storm windows. One can calculate the infiltration as follows:

Crack length equals

7 ft x 2 =	14 ft
3.5 ft x 3 =	10.5 ft
	24.5 ft

Assuming a 10 mile per hour wind, and referring to ref. 2, this yields an infiltration of 0.35 cu ft/min per Linear foot of crack. for a window without a storm window. Therefore total infiltration with a storm window equals:

$$\frac{0.35}{2}\ \frac{\text{cu ft}}{\text{min-ft}} \times 24.5\ \text{ft} \times 16\ \text{window} = 68\ \text{cfm}$$

The equation governing the annual energy savings is:

$$\frac{Btu}{yr}\,(q) = \frac{1.08\ Btu}{hr \times cfm \times deg\ F.} \times cfm \times \frac{deg\text{-}day}{yr} \times \frac{24\ hrs}{day}$$

Therefore:

$$q = 1.08 \times 68 \times 5{,}408 \times 24 = 9.5 \times 10^6\ Btu/yr.$$

In dollar savings this equals:

$$9.5 \times 10^6 \frac{Btu}{yr} \left(\frac{gal}{140{,}000\ Btu \times .7}\right) \left(\frac{\$0.32}{gal}\right) = \$31$$

Therefore the total savings per year by using storm windows equals approximately

$120 + $31 = $151/year

D. <u>Cost Estimated</u>

From manufacturer's data, the cost and installation of a 7 foot by 3 1/2 foot, triple track storm window, using double strength glass is $56 per window. A single pane, sky light storm covering would cost approximately $50.

Therefore total cost would be

16 x $56	=	$896
plus		50
		$946

E. <u>Estimated Useful Life</u>

The estimated useful life of the storm windows is twenty years.

STUDY 24

Cost Benefit Analysis of Installing Plastic Bubble Type Insulation on the Upper Half of all the Windows, at the Highland School Fall River, MA

I. Building Data

A. Date of Construction - 1901
B. Gross Floor Area - 16,968 sq ft.
C. Fuel Burned in Base Year - 19,501 Gal #5 oil.
D. Cost of Fuel in Base Year - $6,500
E. Cost of Fuel per Gallon - $0.38/gal.

II. Summary

The savings due to the installation of plastic, bubble type window insulation as sold by Econ Corp. or equal was calculated and found to be about $170 per year. The installation costs, including preparation costs were estimated to be about $600.

III. Calculations

A. Assumptions

1. The window area is about 1,400 sq ft (78, 3' x 6' windows).

2. During the heating season from Oct 1 to May 1, there are 5,408 deg-days (ref 2).

3. Boiler efficiency is 70 percent.

4. Heat content of #5 oil is 140,000 Btu/gal.

5. "U" value for single pane window equals 1.13 Btu/hr-sq ft-deg F (ref 1).

B. Savings Due to Installation of Plastic Bubble Insulation on the Upper Half of Each Window

From manufacturer's data, the "U" value is lowered from 1.13 Btu/hr-sq ft-deg F. to 0.65 Btu/hr-sq ft-deg F. The savings realized is therefore:

$$(1.13 - 0.65 \text{ Btu/hr-sq ft-deg F}) \left(\frac{1,400}{2} \text{ sq ft}\right) \left(5,408 \ \frac{\text{deg-day}}{\text{yr}}\right)$$

$$\times \left(24 \ \frac{\text{hr}}{\text{day}}\right) = 43.7 \times 10^{6} \text{ Btu/year.}$$

In dollars, this amounts to:

$$(43.7 \times 10^{6} \text{ Btu/yr})\left(\frac{\text{gal}}{140,000 \text{ Btu} \times 0.7}\right)\left(\frac{\$0.38}{\text{gal}}\right) = \$169/\text{year}.$$

C. Cost of Installation

From manufacturer's data, the installed cost of 700 sq ft of insulation is $490.

Cleaning the windows as preparation for installation will cost $105, if local window washing is not available.

Trimming the edges of the windows of paint and other foreign matter will cost another $10.50, assuming 10 percent scraping.

Therefore, the total cost is:

$490 + $105 + $10 = $605.

D. Estimated Useful Lifetime

The distributor of this product will issue a five year warranty on workmanship and material. He has stated to us, however, that the estimated useful lifetime is closer to ten years.

STUDY 25

Cost Benefit Study of Eliminating the Window Areas, on the Apparatus Floor, in the Union Street Fire Station, Attleboro, MA

I. Building Data

A. Date of Construction - 1959
B. Gross Floor Area - 8,000 sq ft
C. Fuel Burned in Base Year - 9077 gal #2 oil
D. Cost of Fuel Burned in Base Year - $3,862
E. Cost of Fuel Per Gallon - $0.425/gal

II. Summary

The energy saved by blocking up the existing windows, with concrete blocks, insulation, and a drywall interior was calculated. The dollar savings was found to be about $460 per year. The installation costs are estimated to be $1,200.

III. Calculations

A. Assumptions

1. Indoor temperature is kept at 65 deg F.
2. Glass area is 434 sq ft, volume of space is 13,000 cu ft.
3. There are 5,923 degree-days during the heating season from Oct 1 to May 1 (ref 1).
4. The infiltration rate through the wall will be reduced from 1-1/2 to 1/4 air changes per hour (ACH).
5. Effects of solar gain through windows will be neglected.
6. The existing windows are of single pane construction with a U value of 1.13 Btu/hr sq ft deg F (ref 2).
7. Windows are replaced by a built up wall consisting of eight inch concrete blocks, three inches of insulation, with a 1/2 inch plaster board interior finish, all having a combined U value of .06 Btu/hr sq ft deg F (ref 3).
8. Heat content of #2 oil is 140,000 Btu/gal. Heating efficiency is 70 percent (ref 5)

B. Transmission Savings by Boarding up the Windows

$$= \frac{(1.13 - 0.06)\text{ Btu}}{\text{hr-sq ft-deg F}} \left(5{,}923\ \frac{\text{deg-days}}{\text{year}}\right) \left(24\ \frac{\text{hr}}{\text{day}}\right) (434\text{ sq ft})$$

$$\times \frac{\text{gal}}{140{,}000\text{ Btu} \times 0.7}) (\$0.425/\text{gal}) = \$280/\text{year}$$

C. Infiltration Savings

$$= \frac{1.08\text{ Btu x min}}{\text{hr x cu ft x deg F}} \times \frac{(1.5-0.25)\text{AC}}{\text{hr x 60}} \times \frac{13000\text{ cu ft}}{\text{AC}} \times$$

$$\frac{5923\text{ deg-day}}{\text{year}} \times \frac{24\text{ hr}}{\text{day}} \times \frac{\text{gal}}{140000\text{ Btu} \times .7} \times \frac{\$0.425}{\text{gal}} = \frac{\$180}{\text{year}}$$

Total savings is therefore:

$$\$280 + \$180 = \frac{\$460}{\text{year}}$$

D. Cost Estimate

1. Cost of eight inch concrete wall finished with 1/2 inch plaster board and three inches of mineral fiber insulation - $3.50/sq ft (ref 4).
2. $350/sq ft x 434 sq ft = $1,519.

E. Estimated Useful Lifetime

Estimated useful lifetime of the insulation is twenty years.

STUDY 26

Cost Benefit Analysis of Replacing Incandescent Lighting with Fluorescent Lights at the Carrol School, Fall River, MA

I. Building Data

A. Date of Construction - approximately 1950
B. Gross Floor Area - 23,914 sq ft.
C. Total Electricity Used in Base Year - 42,721 kWh of electricity
D. Cost of Electricity in Base Year - $2,387
E. Average Cost of Electricity per kWh - $0.056/kWh
F. Incremental Cost of Electricity (8/76) - $0.05/kWh.

II. Summary

The electric savings due to the installation of fluorescent light fixtures was calculated and the estimated savings was found to be $850 per year. The light fixtures, installed, would cost approximately $12,700.

III. Calculations

A. Assumptions

1. There are twelve classrooms approximately 53 feet by 22 feet in area. Each room has eight, symetrically spaced, incandescent lamps, each using 300 watts.

2. There is one primary school room approximately 36 feet by 35 feet. The room has twelve, symetrically spaced incandescent fixtures, using 300 watts each.

3. Lights are in use nine hours per day.

4. School year consists of 170 days.

B. Savings Resulting in the Installation of Fluorescent Light Fixtures in the Classrooms

One cannot directly replace an incandescent with a fluorescent fixture without first examining the difference each one has in light distribution. A round, incandescent bulb, ten feet from the floor, does not have the same light distribution at the floor level as a 4 foot long 1 1/2 inch diameter fluorescent bulb. Variation in overall room brightness is also a factor in designing for fluorescent light fixtures.

Using reference 1, the present lighting system produces about 17 foot-candles of light at the desk level. It is felt that due to light distribution and overall room brightness, no less than 16, four foot fluorescent fixtures should be used in the regular classrooms. This will produce a light level of thirty foot candles at desk level.

In the primary classroom, no less than 21 fixtures should be used. This will yield a light level of 27 foot candles (ref 1).

The energy saved is as follows:

Incandescent:

$$(8\ \frac{\text{lamps}}{\text{room}})\ (12\ \text{rooms})\ (300\ \frac{\text{Watts}}{\text{lamp}}) = 28{,}800\ \text{Watts}$$

$$\text{plus } (12\ \text{lamps})\ (300\ \frac{\text{Watts}}{\text{lamp}}) = 3{,}600\ \text{Watts}$$

for a total of 32,400 Watts.

Fluorescent:

$$(16\ \frac{\text{lamps}}{\text{room}})\ (12\ \text{rooms})\ (100\ \frac{\text{Watts}}{\text{lamp}}) = 19{,}200\ \text{Watts}$$

$$\text{plus } (21\ \text{lamps})\ (100\ \frac{\text{Watts}}{\text{lamp}}) = 2{,}100\ \text{Watts}$$

for a total of 21,300 Watts.

The savings is therefore:

$$32{,}400 - 21{,}300 = 11{,}100\ \text{Watts}$$

Lamps are on nine hours per day for 170 days.

Therefore total hours on equals:

$$9\ \frac{\text{hours}}{\text{day}}\ (170\ \text{days}) = 1{,}530\ \text{hours.}$$

Therefore electrical savings amounts to:

11.1 kW x 1,530 hrs = 16,983 kWh/yr.

at $0.05/kWh - this amounts to $849/yr. (Current cost of electricity)

C. Cost of Fluorescent Lights

From manufacturers data, the installed cost is $60 per fixture. Therefore the total cost is (213 fixtures) @ $60/fixture equals $12,780.

D. Estimated Useful Lifetime

The estimated useful lifetime of the wiring and fixtures is twenty years.

STUDY 27

Cost Benefit Study of Task Lighting at the Concord/Carlisle High School Library, Concord, MA

I. Building Data

A. Date of Construction - 1960
B. Gross Floor Area - 255,000 sq ft
C. Electricity Used in Base Year - 1517,600 kWh
D. Cost of Electricity in Base Year - $65,690
E. Average Cost of Electricity - $0.0432/kWh
F. Incremental Cost of Electricity (8/1976) plus fuel charge - $0.0441/kWh

II. Summary

The initial cost and annual savings resulting from task lighting in the Library were calculated. The existing lighting is from 2 ft x 2 ft 80 Watt fluorescent fixtures and rows of fluorescent strip lights, both mounted in the ceiling. This produces about eighty foot candles at table top level. It was estimated that task lighting would save about $ 230 year. The installed cost was estimated at $2400.

III. Calculations

A. Assumptions

1. There are seventy 2 ft x 2 ft 80 Watt fluorescent light fixtures plus 20 Watts for the ballast which equals 100 Watts per fixture.

2. One half of the 2 ft x 2 ft fixtures could be delamped and replaced with 40 Watt table lamps.

3. Four table lamps per desk would be required, either mounted on the desk top or on the partitions on the desk. There are eight tables on the lower level.

4. The library is open 180 days a year for 10 hours per day.

B. Energy Savings

Based on the assumptions the energy savings would be the difference between the electricity used with all of the ceiling fixtures on and the usage with one half of the ceiling fixtures plus one half of the desk lamps, therefore:

$$\left(70 \text{ lamps} \times \frac{100 \text{ Watts}}{\text{lamp}}\right) - \left(35 \text{ lamps} \times \frac{100 \text{ Watts}}{\text{lamp}} + 4 \text{ desk} \times \frac{160 \text{ Watt}}{\text{desk}}\right)$$

equals 2,860 Watts.

For the year this would be:

$$2860 \text{ Watts} \times \frac{180 \text{ days}}{\text{year}} \times \frac{10 \text{ hrs}}{\text{day}} = 5{,}147 \frac{\text{kilowatt-hr}}{\text{year}}$$

Therefore the savings would be:

$$5{,}147 \frac{\text{kWh}}{\text{year}} \times \frac{\$0.0441}{\text{kWh}} = \frac{\$226}{\text{year}}$$

C. Cost Estimate

Based on manufacturers data, the installed cost per lamp would be $75. A great part of the cost ($60 per lamp) is in the wiring to bring power to the desk tops. Therefore:

$$\frac{\$75}{\text{lamp}} \times 8 \text{ desk} \times \frac{4 \text{ lamp}}{\text{desk}} = \$2400$$

D. Estimated Useful Life

The estimated useful life of the lamps is fifteen years.

STUDY 28

Cost Benefit Study of
Task lighting at the Dunstable Town Hall
Library Dunstable, MA

I. Building Data

A. Date of Construction - 1908
B. Gross Floor Area - 2800 sq ft
C. Electricity Used in Base Year - 5844 kWh
D. Cost of Electricity in Base Year - $400
E. Average Cost of Electricity - $0.068/kWh
F. Incremental Cost of Electricity (8/1976) plus fuel charge - $0.045/kWh

II. Summary

The initial cost and annual savings resulting from task lighting in the library were calculated. The existing lighting is from fluorescent fixtures hung from the ceiling and produces about sixty foot candles at the table top level. It was estimated that the task lighting would save about $70 per year with an installed cost of $600.

III. Calculations

A. Assumptions

1. There are eight existing 8 ft long 200 Watt fluorescent light fixtures plus two 4 ft long 200 Watt fluorescent fixtures both mounted from the ceiling.

2. One half of the existing fixtures could be delamped and replaced with 40 Watt table lamps.

3. A total of eight table lamps would be required.

4. The library is open 200 days a year for 12 hours per day.

B. Energy Savings

Based on the assumptions the energy savings would be the difference between the electricity used with all of the ceiling fixtures on and the usage with one half of the ceiling fixtures plus one half of the desk lamps. Therefore:

$$(9 \text{ lamps} \times \frac{200 \text{ Watts}}{\text{lamp}}) - (5 \text{ lamps} \times \frac{200 \text{ Watts}}{\text{lamp}} + 4 \text{ lamps} \times \frac{40 \text{ Watts}}{\text{lamp}})$$

equals 640 Watts.

For the year, this would be:

$$640 \text{ Watts} \times \frac{200 \text{ days}}{\text{year}} \times \frac{12 \text{ hrs}}{\text{day}} = 1{,}535 \frac{\text{kilowatt-hr}}{\text{year}}$$

Therefore the savings would be:

$$1{,}535 \frac{\text{kWh}}{\text{year}} \times \frac{\$0.045}{\text{kWh}} = \frac{\$68}{\text{year}}$$

C. Cost Estimate

Based on manufacturers data the installed cost per lamp would be $75. A great part of the cost is ($40 per lamp) is in the wiring to bring power to the desk tops. Therefore:

$$\frac{\$75}{\text{lamp}} \times 8 \text{ lamp} = \$600$$

D. Estimated Useful Life

The estimated useful life of the lamps is fifteen years.

121

STUDY 29

Cost Benefit Study of
Task Lighting at the Hill Roberts School
Resource Center, Attleboro, MA

I. Building Data

A. Date of Construction - 1975
B. Gross Floor Area - 8300 sq ft
C. Electricity use in Base Year - 753,300 kWh
D. Cost of Electricity in Base Year - $30,422
E. Average Cost of Electricity - $0.040/kWh
F. Incremental Cost of Electricity (8/1976) plus fuel change - $0.044/kWh

II. Summary

The initial cost and annual savings resulting from task lighting in the resource center were calculated. The existing light fixtures produces about seventy five foot candles at the table top level. It was estimated that the task lighting would save about $110 per year with an installed cost of $1,000.

III. Calculations

A. Assumptions

1. There are thirty two existing 2 ft x 2 ft 100 Watt fluorescent light fixtures mounted in the ceiling.

2. One half of existing fixtures could be delamped and replaced with 40 Watt table lamps.

3. A total of ten table lamps would be required.

4. The Resource Center is open 180 days a year for 10 hours per day.

B. Energy Savings

Based on the assumptions the energy savings would be the difference between the electricity used with all of the ceiling fixtures on and the usage with one half of the ceiling fixtures plus one half of the desk lamps. Therefore:

$$(32 \text{ lamps} \times \frac{100 \text{ Watts}}{\text{lamp}}) - (16 \text{ lamps} \times \frac{100 \text{ Watts}}{\text{lamp}} + 5 \text{ lamp} \times \frac{40 \text{ watts}}{\text{lamp}})$$

equals 1400 Watts.

For the year this would be:

$$1400 \text{ Watts} \times \frac{180 \text{ days}}{\text{year}} \times \frac{10 \text{ hrs}}{\text{day}} = 2519 \frac{\text{kilowatt-hr}}{\text{year}}$$

Therefore, the savings would be:

$$2519 \frac{\text{kWh}}{\text{year}} \times \frac{\$0.044}{\text{kWh}} = \frac{\$110}{\text{year}}$$

C. Cost Estimate

Based on manufacturers data the installed cost per lamp would be $100. A great part of the cost ($.60 per lamp) is in the wiring to bring power to the desk tops. Therefore:

$$\frac{\$100}{\text{lamp}} \times 10 \text{ lamp} = \$1,000.$$

D. Estimated Useful Life

The estimated useful life of the lamps is fiteen years.

REFERENCES

STUDY 1

1. ASHRAE - Handbook of Fundamentals - American Society of Heating, Refrigeration and Air Conditioning Engineers, 1977, page 360-367.

2. ASHRAE Handbook and Product Directory, 1976 Systems - American Society of Heating, Refrigeration and Air Conditioning Engineers, Chap 44.3, Table 3.

3. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

STUDY 2

1. ASHRAE Handbook of Fundamentals, 1972 - (American Society of Heating, Refrigeration, and Air Conditioning Engineers, New York) page 379, equation 4.

2. ASHRAE Guide and Data Book Systems, 1970, page 637, Table 3.

STUDY 3

1. ASHRAE Handbook and Product Directory, 1976 Systems (American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc. - New York, NY), page 37.9

2. University Physics - Sears and Zemansky - Addison-Wesley Publishing Co., Reading, MA, page 274

3. ASHRAE Handbook and Product Directory - 1976 Systems - American Society of Heating, Refrigeration and Air Conditioning Engineers, New York; Chap 44.3, Table 3.

4. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

STUDY 4

1. University Physics - Sears and Zemansky - Addison-Wesley Publishing Co., Reading, MA, page 274

2. ASHRAE Handbook and Product Directory 1975 Equipment, American Society of Heating, Refrigerating and Air Conditioning Engineers, New York, page 26.5, Table 1.

STUDY 5

1. University Physics - Sears and Zemansky - Addison-Wesley Publishing Co., Reading, MA, page 274.

2. ASHRAE Handbook and Product Directory 1975 Equipment, American Society of Heating, Refrigerating and Air Conditioning Engineers, New York, page 26.5, Table 1.

STUDY 6

1. Engineering Weather Data - Air Force, Army and Navy Manual
AFM88-8 Chap. 6
TM 5-785
NAVFAC P-89
U.S. Government Printing Office, Washington, 1967, page 277.

2. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

3. Climatological Data for New England, Volume 87, No. 7 National Oceanic and Atmospheric Administration, Page 40.

STUDY 7

1. Air Force Army and Navy Manual - Engineering Weather Data
AFM 88-8 Chap. 6
TM 5-785
NAVFAC P-89
U.S. Government Printing Office - Washington: 1967, page 277.

2. ASHRAE Handbook and Equipment Directory - 1975 (New York: American Society of Heating, Refrigeration and Air Conditioning Engineers, 1975) Chap. 24, page 248.

STUDY 8

1. ASHRAE Handbook and Product Directory, 1975 Equipment (New York, American Society of Heating, Refrigerating and Air Conditioning Engineers) page 24.5.

2. ASHRAE Handbook of Fundamentals, 1972 Equation 54, page 422.

STUDY 9

1. ASHRAE Handbook and Product Director, [illegible] Equipment (New York, American Society of Heating, Refrigerat[illegible] and Air Conditioning Engineers) page 24.5.

2. ASHRAE Handbook of Fundamentals, 1972 Equation 54, page 422.

STUDY 10

1. ASHRAE Handbook and Product Directory, 1975 Equipment (New York, American Society of Heating, Refrigerating and Air Conditioning Engineers) page 24.5.

2. ASHRAE Handbook of Fundamentals, 1972 Equation 54, page 422.

STUDY 11

1. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

STUDY 12

1. ASHRAE Handbook and Product Directory - 1975 Equipment, page 24.5

STUDY 13

1. ASHRAE Handbook of Fundamentals, 1972 (New York, American Society of Heating, Refrigerating and Air Conditiong Engineers, 1972), page 367, Table 4H.

2. ASHRAE Standard 90-75 Energy Conservation in New Building Design (New York 1975) Page 16.

3. ASHRAE Handbook and Product Directory, 1975 Equipment page 24.5

4. Climatological Data for New England, Volume 87, No. 7, National Oceanic and Atmospheric Administration, Page 40.

STUDY 14

1. ASHRAE - Handbook of Fundamentals (New York - American Society of Heating, Refrigeration and Air Conditioning Engineers, 1972) page 367, Table 4H.

2. ASHRAE Standard 90-75 - Enefgy Conservation in New Building Design

3. Air Force, Army, and Navy Manual, Engineering Weather Data
AFM 88-8 Chap. 6
TM 5-785
NAVFAC P-89
U.S. Government Printing Office - Washington 1967 page 277.

4. Principles of Heat Transfer - Frank Kneith, International Textbook Company, Scranton, PA, 1965, page 17, equation 1-22.

5. Climatological Data for New England, Volume 87, No. 7, National Oceanic and Atmospheric Administration, Page 40.

6. ASHRAE Handbook and Product Directory, 1976 Systems - American Society of Heating, Refrigeration and Air Conditioning Engineers, Chap 44.3, Table 3.

7. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

STUDY 15

1. ASHRAE Handbook of Fundamentals (New York: American Society of Heating, Refrigeration and Air Conditioning Engineers, 1972) page 368-69).

2. Air Force, Army and Navy Manual Engineering Weather Data
AFM88-8 Chap. 6
TM 5-785
NAFVAC P-89
U.S. Government Printing Office - Washington, 1967, page 277

3. Principles of Heat Transfer - Frank Kreith, International Textbook Company, Scranton, PA 1965, page 17, equation 1-22.

4. ASHRAE Handbook and Product Directory, 1976 Systems (New York, American Society of Heating, Refrigeration and Air Conditioning Engineers, 1976), page 43.9, table 4.

5. Climatological Data for New England, Volume 87, No. 7, National Oceanic and Atmospheric Administration, Page 40.

6. ASHRAE Handbook and Product Directory, 1976 Systems - American Society of Heating, Refrigeration and Air Conditioning Engineers. Chap 44.3, Table 3.

7. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

STUDY 16

1. CLIMATOLOGICAL Data for New England - Volume 87 No. 7 - National Oceanic and Atmospheric Administration, Page 40.

2. ASHRAE - Handbook of Fundamentals, American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1972. Chap 20, page 360-368

3. ASHRAE Standard 90-75

4. ASHRAE Handbook and Product Directory, 1975 Equipment, Page 24.5

STUDY 17

1. CLIMATOLOGICAL Data for New England - Volume 87 No. 7 - National Oceanic and Atmosphoric Administration, page 40.

2. ASHRAE Handbook of Fundamentals - American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1972, page 360-367.

3. ASHRAE Standard 90-75 - Energy Conservation in New Building Design.

4. ASHRAE Handbook and Product Directory - 1976 Systems American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, Chap 44.3, Table 3.

5. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

STUDY 18

1. ASHRAE Handbook of Fundamentals, 1972 (New York, American Society of Heating, Refrigerating and Air Conditioning Engineers, 1972), page 367, Table 4H.

2. ASHRAE Standard 90-75 Energy Conservation in New Building Design (New York 1975) Page 16.

3. ASHRAE Handbook and Product Directory, 1975 Equipment page 24.5

4. Climatological Data for New England, Volume 87, No. 7, National Oceanic and Atmospheric Administration, Page 40.

STUDY 19

1. CLIMATOLOGICAL Data for New England - Vol. 87. No. 7, National Oceanic and Atmospheric Administration, Page 40.

2. ASHRAE Handbook of Fundamentals - American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1972; pages 360-367.

3. ASHRAE Standard 90-75 - Energy Conservation in New Building Design.

4. Building Construction Cost Data - 1976 - Robert Snow Means Company, Duxbury, MA, 1976.

5. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

STUDY 20

1. Climatological Data for New England, Volume 87, No. 7 - National Oceanic and Atmospheric Administration, Page 40.

2. ASHRAE Handbook of Fundamentals American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1972, page 360-367.

3. System Design Manual - Part 1 Load Estimating - Carrier Corp., Carrier Parkway, Syracuse, NY, 1961; Page 1-95, table 44.

4. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

STUDY 21

1. ASHRAE Handbook of Fundamentals (American Society of Heating, Refrigeration and Air Conditioning Engineers), New York, 1972.

2. System Design Manual - Part 1, Load Estimating - Carrier Corp. Carrier Parkway, Syracuse, NY, 1961, page 1-95, Table 44.

3. Climatological Data for New England, Volume 87, No. 7, National Oceanic and Atmospheric Administration, page 40.

4. ASHRAE Handbook and Product Directory 1975 Equipment, page 24.5

STUDY 22

1. ASHRAE Handbook of Fundamentals (American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1972.

2. System Design Manual - Part 1, Load Estimating - Carrier Corp., Carrier Parkway, Syracuse, NY, 1961, page 1-95, Table 44.

3. Climatological Data for New England, Volumn 87, No. 7, National Oceanic and Atmospheric Administration, Page 40.

4. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

STUDY 23

1. ASHRAE Handbook of Fundamentals - American Society of Heating Refrigeration and Air Conditioning Engimeers, New York, 1972, Pages 360-367.

2. CLIMATOGICAL Data for New England - Volume 87 No. 7, National Oceanographic and Aerospace Administration, Page 40

3. System Design Manual Part 1 - Load Estimating - Carrier Corp., Carrier Parkway, Syracuse, NY, 1961, page I-95, Table 44.

4. Engineering Weather Data - Air Force, Army and Navy Manual
AFM 8-88, Chap 6.
TM5-785,
NAVFAC P-89
U.S. Government Printing Office, Washington, 1967, page 277.

5. University Physics - Sears & Zemansky, Addison Wesley Publishing Co., Reading, MA, 1957, page 274.

STUDY 24

1. Climatological Data for New England, Volume 87, No. 7, National Oceanic and Atmospheric Administration, Page 40.

2. ASHRAE Handbook of Fundamentals, 1972 page 370, Table 8.

3. ASHRAE Handbook of Fundamentals, 1972 page 366, Table 4F.

4. Means Building Construction Cost Data, 1976 34th Edition (Robert Snow Means Co., Duxbury, MA).

5. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

STUDY 25

1. Westinghouse Lighting Handbook - Westinghouse Lamp Division, Westinghouse Electric Corp., Bloomfield, NJ, 1963, Chap 6.

STUDY 26

1. CLIMATOLOGICAL Data for New England - Volume 87 No. 7 - National Oceanic and Atmospheric Administration, Page 40.

2. ASHRAE Handbook of Fundamentals - American Society of Heating, Refrigeration and Air Conditioning Engineers, New York 1972, page 360-367.

3. ASHRAE Standard 90-75 - Energy Conservation in New Building Design.

4. ASHRAE Handbook and Product Directory, 1975 Equipment, page 24.5

5. Building Construction Cost Data - 1976 - Robert Snow Means Co., Duxbury, MA, 1976.